AFIT/GSE/ENY/95D-01

A SYSTEMS ENGINEERING APPROACH TO AIRCRAFT KINETIC KILL COUNTERMEASURE TECHNOLOGY: DEVELOPMENT OF AN ACTIVE AIR DEFENSE SYSTEM FOR THE C/KC-135 AIRCRAFT

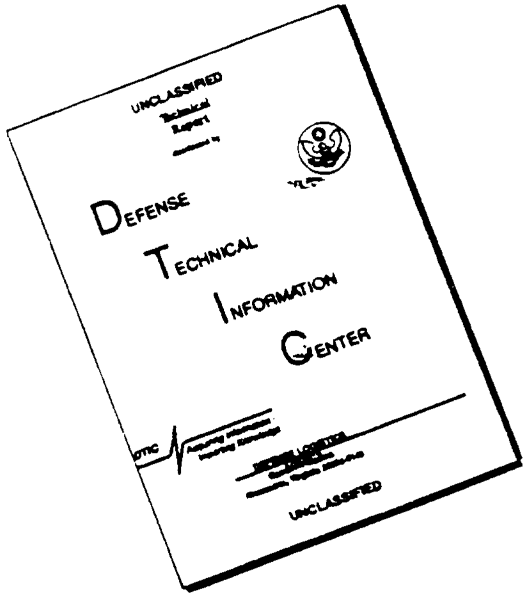
THESIS (Vol 1 of 2)

Mark C. Cherry, Captain, USAF
Bruce R. Dewitt, Major, USAF
Christopher G. Dusseault, Captain, USAF
Joel J. Hagan, Captain, USAF
Brian S. Peterson, Captain, USAF

AFIT/GSE/ENY/95D-01

Approved for public release; distribution unlimited

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

AFIT/GSE/ENY/95D-01

A SYSTEMS ENGINEERING APPROACH TO AIRCRAFT KINETIC KILL COUNTERMEASURE TECHNOLOGY: DEVELOPMENT OF AN ACTIVE AIR DEFENSE SYSTEM FOR THE C/KC-135 AIRCRAFT

THESIS
(1 of 2)

Presented to the Faculty of the Graduate School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment for the Degree of

Master of Science in Systems Engineering

Mark C. Cherry
Captain, USAF

Bruce R. Dewitt
Major, USAF

Christopher G. Dusseault
Captain, USAF

Joel J. Hagan
Captain, USAF

Brian S. Peterson
Captain, USAF

December 1995

Table of Contents

Preface

Increasing costs of new aircraft for both the military and civilian purchasers have increased the need for self-protection of these very valuable resources. The ability of many terrorist and paramilitary groups to obtain shoulder launch surface to air missiles increase the risk of these high dollar assets to the low cost weapon. The striking of aircraft with low cost surface to air missiles is a definite concern of the United States Air Force (USAF) and considerable research is being pursued in the areas of self-defense and automatic defense of our aircraft.. This is the motivation that led the System Engineering Design Team to the systems design of an aircraft anti-missile system.

This thesis uses the systems engineering approach to determine an anti-missile system that is both affordable and effective for use on a KC-135 aircraft. The research combines the disciplines of aeronautics, control design, structures analysis, and statistical modeling to determine a candidate design. The thesis represents both a structured approach to decision making and abstract thinking in design development. The successful application of the systems engineering process in this project will hopefully show the true benefit of approaching an intricate design problem with consistent thought and processes. Unlike many engineering and acquisition efforts, extreme systematic self-discipline prevented the team from focusing on either the most technological or most costly answer.

We would like to thank Lieutenant Colonel Kramer for his light managerial hand and questioning demeanor. We thank the many civilian contributors who provided

available data and time to answer our multitude of questions; Arnis Mangolds (Foster-Miller Inc), Frank Stoddard (TRW), Ronald Stanislaw (Westinghouse) and Bob Stevens (Lockheed Sanders). We also would like to thank Dr. George Voegle of Wright Laboratories, the key to our missile knowledge.

Finally, we would like to thank all the girls that turned down Joel for dates in 1994 and 1995. Without them, this project would be at a standstill.

The Systems Engineering Team

List Of Figures

List of Tables

Abstract

Modern Surface to Air Missiles (SAMs) present a significant threat to today's military and civilian aircraft. Current countermeasure systems such as flares and chaff rely on decoying the missile threat and do not provide adequate protection against advanced computerized missiles (Schaffer, 1993:1). An aircraft defense system that actively seeks out and defeats an incoming missile by placing a physical barrier in the missile's path offers a promising alternative to current countermeasures technology. This thesis reports the preliminary design of an active aircraft defense system for the protection of the C/KC-135 aircraft from SAMs. The developed system utilizes a kinetic kill mechanism to protect the aircraft from shoulder launched missiles while the aircraft is in the takeoff and climb-out configurations. Both smart anti-missile expendables and dumb projectile expendables are evaluated. The iterative Systems Engineering approach is used to narrow the solution set to the optimal design. The final outcome is the refined design of two candidate aircraft defense system employing a kinetic kill mechanism. Both systems utilize a modified ultra-violet tracker and employ one of two types of nets, one made out of Detonation Cord™ and the other made out of Spectra™.

A SYSTEMS ENGINEERING APPROACH TO AIRCRAFT KINETIC KILL COUNTERMEASURE TECHNOLOGY: DEVELOPMENT OF AN ACTIVE AIRCRAFT DEFENSE SYSTEM FOR THE C/KC-135 AIRCRAFT

I. Introduction

1.1 Background

In 1992, an SA-7 shoulder launched missile shot down an Italian military transport aircraft delivering humanitarian aid to Bosnia. This event temporarily stopped humanitarian relief operations and served to open the public's eye to the growing threat of shoulder launched missiles (Morrocco, 1992:42). While one of the more publicized recent missile attacks, the Bosnian incident is by no means an isolated event. Sophisticated shoulder launched surface-to-air missiles (SAMs), with their ever increasing effectiveness, are becoming more and more common on today's military battlefield. Equally alarming is the growing terrorist threat that SAMs present to the civilian community. Between 1983 and 1992, 34 civilian aircraft were shot down by SAMs worldwide, resulting in 651 fatalities (Shaffer, 1993:3). The current unstable political and economic state of the world all but guarantees the escalation of this threatening trend.

Possibly the most alarming fact about modern shoulder launched missiles is the relative ease by which an individual can acquire one. The United States estimates that several hundred Stinger missiles are currently being sold on the black market by Afghan rebels. Many different organizations are known to have shown interest in these missiles including Iran, the Irish Republican Army, and Colombian drug traffickers (Hughes,

1992:32). The recent break-up of the Soviet Union increases the possibility of modern SAMs entering the market place, including the SA-14. The SA-14 is an extremely advanced shoulder launched missile, considered by experts to be more capable than the Stinger in terms of performance and ability to overcome infra-red countermeasures (Doherty, 1995).

Currently, flares and chaff provide the primary SAM defense system for aircraft. While these systems are reasonably effective against infra-red and radar guided missiles, they lack effectiveness against many other targeting methods such as laser guided missiles (Schaffer, 1993:6). Compounding this lack of effectiveness are the advances on-board computers have brought to missile technology. Today's shoulder launched SAMs possess the capability of identifying the decoying characteristics presented by flare and chaff defensive systems (Fulghum, 1992:57). These advancements severely limit the usefulness of current flare and chaff systems in protecting U.S. aircraft. The "bottom line" is that advanced SAM technology is rendering current missile defense systems, which are already marginally effective, virtually obsolete (Shaffer, 1993:1).

Clearly, combating this advanced missile threat requires an innovative approach to aircraft defense. Instead of trying to avoid the SAM, it is proposed that an active aircraft defense system be developed which seeks out an inbound missile and destroys it.

1.2 Objective

The purpose of this thesis is to define the optimal active aircraft defense system for protecting a C/KC-135 aircraft against a shoulder launched surface to air missile while

the aircraft is in the takeoff and climb-out configurations. This objective is accomplished by employing the Systems Engineering Process which is described in section 1.3 of this thesis. Section 2.1 presents the rationale for choosing this specific aircraft type and problem scenario.

1.3 Systems Engineering Process

There are several complicated and involved questions that must be answered before the optimal aircraft defense system described in section 1.2 can be realized. For example, how accurate does a missile tracking system have to be in order to intercept a shoulder launched missile? What is the best type of expendable for destroying shoulder launched missiles? What is the best way to launch and deploy this expendable? The overriding problem in answering these complicated questions is sorting through an almost limitless solution set and arriving at the optimal system design. These questions are answered in this thesis by following a systematic design approach resulting in the definition of an optimal aircraft defense system.

The GSE-95D Systems Engineering Team followed the Systems Engineering Process defined by A. D. Hall (Kramer, 1994). This design process, which is summarized in sections 1.3.1 through 1.3.7, is an iterative process. Initially, all feasible solutions to a particular design problem are considered. Basic information about these solutions are gathered in order to evaluate which solutions are better than others. Each iteration of the Systems Engineering Process involves gathering more information on each candidate system and performing a more detailed design on those systems. As successive

evaluations are performed during each iteration, the solution set of the problem is narrowed. The end result of these successive iterations is the best solution to the problem.

The evaluation of each candidate system is based on how well a system performs relative to characteristics of the system which the design engineer and other key decision makers deem important. It is rarely possible to define the quality of a system based on a single parameter. The Systems Engineering Process enables a design engineer to evaluate systems in terms of multiple parameters which need not necessarily be related.

1.3.1 Problem Definition. The first step in the Systems Engineering Process is *Problem Definition*. The purpose of *Problem Definition* is to develop a clear picture of the problem under consideration. During this phase of the Systems Engineering Process, four aspects of the problem are defined. First, the needs of the system must be determined. Needs are certain system characteristics that the designer would like to have, but are not necessarily required. Initially, this list is long and idealistic. Through various interations this list is narrowed down to the most relevant issues. Second, constraints on the system are defined. In contrast to needs, these are characteristics that the system must have. Without them, the system is not viable. Examples of these characteristics are physical constraints, monetary constraints or operational constraints. Third, the alterables, those aspects of the system over which the designer has control, are listed. These are the "knobs" which the designer turns in order to develop a well designed system. Finally, the actors, those individuals who will affect or are affected by the system design, are defined.

1.3.2 Value System Design. Once the problem is clearly understood, the next

step is to create an explicit framework for evaluation and comparison of alternative solutions. The *Chief Decision Maker* for the team, generally the sponsor for the project, builds this framework around trade-off areas he or she feels are crucial to determining the optimal solution. Characteristics commonly considered as design trade-offs include system effectiveness, system maintainability, and life cycle cost. This process normally takes the form of a tree structure. At the top of the tree is the overall goal of the system, or, in other words, what you want the system to accomplish. For example, if the system is a pair of skis, the overall goal may be to develop the fastest slalom skis possible. Just below this goal in the tree structure is a definition of the "top level" characteristics which describe those aspects of the system which are important to achieving the overall goal. In the case of skis, for example, these characteristics may be the ability to turn sharply, the ability to handle small moguls, and the ability to attain maximum speed in the straight-aways. These top level characteristics are further subdivided until system characteristics are defined which can be quantified by a specific measurable. Again, using the ski example, these measurables could be such things as the skis' rigidity, camber, and surface texture. Figure 1.1 presents a sample *Value System Design.*

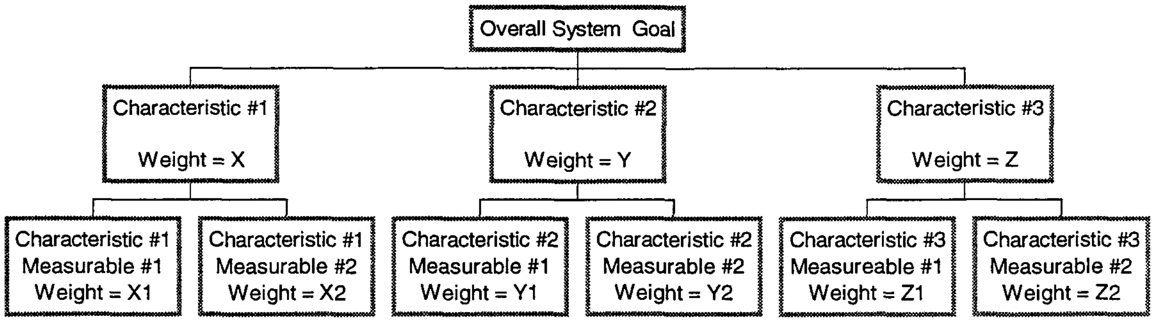


FIGURE 1.1 Sample Value System Design

1.3.3 System Synthesis. The next step is the "brain storming" stage. All potential system designs, regardless of their initial plausibility, are discussed. The only limiting factor at this stage is to ensure these designs do not violate constraint requirements defined in the *Problem Definition* phase. At each iteration of the Systems Engineering Process, the list of possible system designs is narrowed and the design of those systems remaining on the list are further refined.

1.3.4 System Modeling. With the trade-off areas and potential solutions defined, effort is placed on modeling the trade-off characteristics defined in *Value System Design*. The purpose of the model is to generate a means of quantifying potential solutions, thereby allowing for a numerical comparison of the candidate systems. Models can take almost any form. Everything from a simple subjective 1 to 10 rating scale to an extremely detailed computer simulation is considered acceptable. The only requirement for a model is that it must quantify the particular system characteristic to the level of accuracy desired by the design team at the point it is being used.

1.3.5 System Evaluation. Comparisons of the candidate aircraft defense systems

on an equivalent level is essential for an equitable evaluation. Unfortunately, a majority of the system characteristics defined in the *Value System Design* phase and quantified in the *Modeling* phase do not have the same unit of measure. Consequently, they cannot be directly compared. In order to make an accurate comparison, the characteristics of each system must be mapped to a common scale. This is accomplished using utility charts. These charts allow an individual to rate how useful a particular system characteristic is in achieving the overall system objective. For example, a system which has a probability of kill (PK) of 0.5 is not very useful and therefore, as depicted in Table 1.1, only has a utility rating of 20 out of 100. A system with a PK of 0.9, however, is much more useful and has a utility rating of 80 out of 100.

TABLE 1.1 Probability of Kill Utility Chart

PK	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Utility	100	80	60	40	30	20	15	10	5	1

One system characteristic is not necessarily as important as another. The PK of an aircraft defense system could be considered more important than the monetary cost of the system. In order to quantify the relative importance between system characteristic defined in *Value System Design*, each characteristic is assigned a weighting factor. The sum of the weighting factors for each level of the tree structure defined in section 1.3.2 must sum to 1.0. For example, System A presented in Figure 1.1 is described by three characteristics. The sum of the weights X, Y, and Z will all equal 1.0. Similarly the sum of X1, X2, Y1, Y2, Z1, and Z2 will all equal 1.0. The sum of the subcharacteristic weights will equal the weight of the top level characteristic, i.e., X = X1 + X2. This

weighting system can accentuate the importance of certain system characteristics and diminish others and, hence, must be carefully determined and documented.

Clearly, the data calculated for each measurable from a specific model are not as accurate for one system as for another. This is due to the fact that some systems may exist in operational form and, consequently, are more clearly understood, while other systems may exist purely on paper and, therefore, are not as well defined. In order to equitably compare systems of diverse fidelity, a confidence rating is assigned to the measurable for each particular system. A confidence rating of 1 indicates the measurable data is completely accurate while a rating of 0 indicates that a measurable value is selected purely at random.

The product of the weight and the utility score defined in this phase of the Systems Engineering Process is calculated for each system characteristic. The sum of these products results in the *Raw Utility Score* of a candidate system. When the sum is calculated using confidence level multipliers, the resulting score is the *Discounted Utility Score* of a candidate system.

1.3.6 Decision Making. The *Raw Utility Score* and *Discounted Utility Score* serve as objective measures to determine which candidate system is the best. The higher the score, the better the system. Although this may seem to be a "cut and dry" method of choosing the optimal system, one must be cautious of blindly following the numbers and not thinking about the decision. The *Decision Making* step of the Systems Engineering Process uses the tools of *Raw* and *Discounted Utility Scores* as good filters with which to eliminate the poorer systems. Beyond this, a good deal of thought must go into why the

remaining systems have the scores that they do, and whether or not the top scoring system is truly the best or one if one of the other systems is better. Clearly, this step of the Systems Engineering Process involves significant engineering judgment. The end result of this step is the decision of which candidate systems is the best.

1.3.7 Implementation. Once the decision is made as to which is the best system, action must be taken. It is obviously useless to make a decision and do nothing with it. Implementation can take several forms such as developing a more detailed design, building a prototype, or in the case of the GSE-95D Systems Engineering Team, compiling the results into the best Systems Engineering Project AFIT has ever seen.

1.4 Outline

1.4.1 Design Iterations. The GSE-95D Systems Engineering Team followed the Systems Engineering Process described in section 1.3 in determining the optimal aircraft defense system. Three iterations of the Systems Engineering Process were accomplished. All three iterations entailed a narrowing of the possible candidate aircraft defense systems to an increasingly smaller solution set. At the same time, the degree of detailed study given to the candidate systems increased with each iteration. The end product of the third iteration was the optimal design of two aircraft defense systems.

1.4.2 Chapters. The following seven chapters parallel the seven steps in the Systems Engineering Process. Interwoven within each chapter is a description of the three iterations. Chapters II through V track the first four steps of the SE process, *Problem Definition* through *System Modeling*. The results of this thesis are presented in

Chapter VI, *System Evaluation*. The conclusions are presented in Chapter VII, *Decision Making*. Finally, the recommendations are presented in Chapter VIII, *Implementation*.

II. Problem Definition

The GSE-95D System Engineering Team established the problem definition in the first iteration of the Systems Engineering Process and adhered to it throughout the following two iterations. Although the problem definition was reviewed at the beginning of each of the following two iterations to ensure its continued applicability, the GSE-95D philosophy with regard to the problem definition was that it must be firmly established at the beginning of this project. Time and resource constraints do not afford the luxury of significant changes to the problem definition. For this reason, a great deal of time and thought was given to this definition during the first iteration. Presented in this chapter is a statement of the problem, the current aircraft defense systems, the needs that the system must meet, the constraints which limit the system, a definition of the variables which are altered throughout the design in order to optimize the system, and a listing of the actors. The final section of this chapter discusses limitations on the problem definition due to the desire of the GSE-95D Systems Engineering Team to keep this thesis unclassified.

2.1 Problem Statement

Modern SAMs present a significant threat to today's military and civilian aircraft. Current countermeasure systems such as flares and chaff rely on decoying the missile and do not provide adequate protection against advanced computerized missiles (Schaffer, 1993:1). The use of an active aircraft defense system to protect aircraft from modern

missiles offers a promising alternative to current countermeasure technology. Active aircraft defense systems seek out an incoming missile and deploy a physical barrier between the target aircraft and the missile threat. This action defeats the missile through physical contact and does not rely on a potentially unreliable guidance deception. A feasibility study needs to be undertaken to explore the potential of an active aircraft defense system and to determine the optimal system configuration.

Two types of active aircraft defense systems are possible, 'smart' and 'dumb'. Smart systems utilize a guided missile to actively track and destroy an incoming missile. Dumb systems track the missile using sensors on board the host aircraft and deploy an expendable to a pre-determined intercept location. Current efforts are underway in the 'black' project world on the use of smart aircraft defense systems. The GSE-95D Systems Engineering Team chose to focus on dumb aircraft defense systems, but any unclassified information related to smart system development should be obtained. This information provides a foundation for dumb system development and establishes a basis for comparison between the two systems.

Noting the excessive magnitude of developing such a system which would be effective for all aircraft under all scenarios, the GSE-95D Systems Engineering Team, in conjunction with the sponsors of this thesis, narrowed the scope of this problem to developing a system specifically for the C/KC-135 aircraft. The Systems Engineering Team chose this particular aircraft for two reasons. First, it is one of the U.S. Air Force's most extensively used airframes. Second, the C/KC-135 is considered a force-multiplier aircraft. If shot down, the effectiveness of the aircraft it refuels is significantly

diminished. The scope of the problem is further narrowed by only considering the development of this defense system for optimal effectiveness when the C/KC-135 is in the takeoff and climb-out configurations. This scenario is chosen based on the extreme vulnerability of the aircraft during these phases of flight. The C/KC-135 has little excess power with which to maneuver and little time to react. With such little time, it is unlikely that current defense systems such as flares or chaff would be effective. It is assumed in this scenario that the airfield from which the C/KC-135 is taking off is secured, but is still vulnerable to terrorist attack by small groups. This scenario is similar to the recent humanitarian relief operation in Somalia. It is further assumed that these terrorist are able to get as close as 914 m (3000 ft) to the runway, but will attack from no further away than 2134 m (7000 ft).

2.2 Current Defense Systems

Several defense systems currently exist or are being developed to protect military aircraft against the threat of missile attack. The majority of these defense systems attempt to either decoy, blind, or attack the threat missile. This section describes defense systems currently proposed or under development which employ these methods of defeating a threat missile.

2.2.1 Decoying The Missile. Decoying refers to the act of confusing the missile such that the missile is not certain of its target's location. A standard method used for many decades in order to decoy Infrared (IR) or heat-seeking missiles has been to dispense flares from the aircraft. IR missiles are attracted to these heat sources and,

subsequently, away from the aircraft. Recent advances in flare technology have resulted in flares that are able to cover a wider range of the IR spectrum as well as flares that are able to better mimic the IR signature of particular aircraft.

A standard method used in order to decoy radar-guided missiles has been to dispense chaff from the aircraft. Chaff is simply strips of thin metal such as tin-foil. Radar from the missile's tracking system bounces off the chaff as well as the aircraft. The multiple return signals from the chaff make it difficult for the missile's tracking system to discern the location of the aircraft. Recent advances in chaff development have resulted in the ability to automatically cut chaff to the proper length as it is dispensed from the aircraft such that the chaff more closely approximates the radar signature of the aircraft the missile threat it is tracking.

2.2.2 Blinding The Missile. Missiles that track their target do so by being able to "see" the target. "Seeing" involves receiving a specific type of energy signal such as IR, Ultra Violet (UV), or pulse doppler radar. If it is possible to block this signal and "blind" the missile, the missile will be unable to track and subsequently hit its target.

The most common method of "blinding" the missile is jamming. Several systems exist which are designed to jam pulse-Doppler radar guided missiles. Systems such as the ALQ-184 and ALQ-131 are designed to perform in several modes. They can radiate high energy Gaussian noise within the sensing band of the missile, perform "range gate pull-off" and perform "velocity gate pull-off". The Gaussian noise generator simply allows the aircraft signal to get lost in a cloud of noise. "Range gate pull-off" tricks the missile into believing the targeted aircraft is either much closer or much further away than it

really is. "Velocity gate pull-off" tricks the missile into believing the targeted aircraft is much slower or faster than it really is, causing errors in the intercept calculations.

IR missiles can be jammed using directed energy. Directed Infrared Counter Measures (DIRCM) is a system designed to jam IR guided missiles. DIRCM involves aiming a relatively high-intensity beam of IR energy at the threat missile (New Army Jammers Undergo Tests, 1993). Companies actively developing DIRCM technology include Northrop, Lockhead Sanders, and Loral. All three companies are currently developing DIRCM systems for the British Defense Ministry (Hughes, 1994:1). Northrop's DIRCM system relies on a Missile Attack Warning System (MAWS) such as the Cincinnati Electronics AAR-44 to initially detect and steer the DIRCM beam onto the missile. Once detected and properly aligned, a 256 by 256 element mercury cadmium telluride focal plane array, collocated with the beam in the turret of the system, takes over and tracks the missile (Nordwall, 1993:62). Currently, at least two Northrop DIRCM systems are required to protect a C-130 aircraft. Due to its larger engine exhaust cross-sectional area and greater aerodynamic heating, an F-15 aircraft would require three or more DIRCM systems for protection. To protect aircraft such as the F-15, Northrop is also developing a laser jamming system which works on the same principle of blinding the missile as does the previously defined DIRCM system (Nordwall, 1993:61). The distinction between the two systems is that the amount of directed energy the LASER system places on the seeker head of a missile is greater than the DIRCM system. Lockhead Sanders is currently developing a DIRCM system called the Advanced Tactical Infrared Countermeasures (ATIRCM) system which also employs a LASER in order to

blind the threat missile. Lockheed Sanders in developing this system for the U.S. Army's UH-60 helicopter. The U.S. Air Force's Joint Strategic-Tactical Aerial Reconnaissance System (JSTARS) program office has also expressed interest in using ATIRCM to protect the JSTARS aircraft (Hughes, 1994:57). Unlike the ATIRCM system which employs a coherent LASER beam, Loral's DIRCM system focuses non-coherent infrared energy on an incoming missile (Hughes, 1994:57). The Loral DIRCM system focuses the energy from a cesium lamp into a 15° wide beam. This beam can pivot 10° above and 70° below the horizon and can rotate through 360°.

Another method of "blinding" missiles under development is to physically block the missile's sensor. In 1994, the Missile Space Intelligence Agency proposed the development of system called Polyphemus designed to "blind" a missile. Polyphemus consists of a munition, self propelled or fired, that deploys a cloud of material at a predetermined distance in front of a threat missile. When the missile enters the cloud, its seeker head is coated with the dispersed material which effectively blocks the energy the missile seeker requires to track its target (Boyer, 1994:1-2).

2.2.3 Attacking The Missile Compared to aircraft defense systems which attempt to decoy the missile such as flares, chaff, and blinding systems, systems which attack the missile provide a much better guarantee that the missile threat is eliminated. In this context, attacking refers to seeking out the missile and actively causing its destruction.

One promising concept for the next generation active aircraft defense systems is the use of kinetic kill expendables to destroy an in-bound missile. The term "kinetic kill

expendable" refers to a projectile which impacts a missile in order to destroy it. The basic philosophy behind kinetic kill expendables is to place a physical barrier in the path of the approaching missile, thereby defeating the threat. This concept of placing a 'brick wall' between the missile and the aircraft presents two advantages. The first advantage is that any type of SAM can be destroyed since the mode of destruction relies primarily on the transfer of kinetic energy to eliminate the missile threat, not a specific guidance property such as heat or radar signature. The second advantage is derived from the fact that the aircraft defense system knows exactly where the missile is headed: at the aircraft. Specifically, this knowledge significantly narrows the required placement of the 'brick wall' in order to eliminate the missile threat.

Kinetic kill expendables are currently being developed by such companies as TRW and Raytheon. TRW has proposed the Aircraft Close In Defense System or ACIDS, a guided, self-propelled missile that is designed to detonate in close proximity to a threat missile. Effectively, ACIDS is an anti-missile missile. Section 4.3.1 further describes in detail the ACIDS system (Stoddard, 1995).

Kinetic kill expendables are not limited to protecting aircraft. Raytheon has developed a similar system called the Small Low Cost Interceptor Device (SLIDS) for the protection of the U.S. Army's Bradley Fighting Vehicle. This system consists of a passive IR detection system, a laser range finder which identifies and tracks the incoming threat, a launch system which is able to cover 360°, a semi-active laser guidance system, and a fly-by-optic wire low-cost interceptor designed to meet all missile threats and top-down attacks from mortars. Similar to ACIDS, SLIDS is an anti-mortar missile system.

2.3 Needs

The following list highlights the primary requirements for the aircraft defense system. These specifications provide the basic parameters under which a successful active aircraft defense system should operate.

The aircraft defense system **should**:

1. Detect all incoming shoulder launched SAMs
2. Track all incoming shoulder launched SAMs
3. Destroy all incoming shoulder launched SAMs with a PK > 90%
4. Operate in all weather conditions encountered by host aircraft
6. Require minimum training for flight crews and support personnel
7. Require minimum maintenance and support
8. Have low life cycle cost
9. Operate effectively for at least the next 20 years
10. Prevent the threat missile from entering the "Lethal Sphere" around the aircraft defined by a 30 m (100 ft) radial distance from the aircraft center of gravity

Need number 9 describing the duration of operational effectiveness is based on the expected lifetime of an existing aircraft defense system, the flare system currently used on the B-1B aircraft. The radius of the Lethal Sphere defined in need number 10 is based on Air Combat Command's (ACC's) lethal distance definition which is the longest distance from the aircraft's center of gravity (CG) to any point on the aircraft, in the case of the C/KC-135 this is to the wing tip, plus two times the effective kill radius of the missile. (Brunhelder, 1995). All of the needs listed are considered by the GSE-95D Systems Engineering Team to be logical attributes of an effective aircraft defense system.

2.4 Constraints

The following list presents the constraints imposed on the aircraft defense system. For the system to provide a feasible defense to the missile threat, it must adhere to all of the following restrictions.

The aircraft defense system **must**:

1. Be designed for use on a C/KC-135 aircraft
2. Be designed for optimal performance when the C/KC-135 is in the take-off and climb-out phases of flight
3. Have an expendable that fits into the existing volume of the flare bucket being used on the C/KC-135

The aircraft defense system **must not**:

1. Require more than an Air Force Class II modification to the host aircraft.
2. Degrade the handling qualities of the closed loop aircraft (with augmentation) to less than Level 1 Flying Qualities as measured by the Cooper-Harper rating scale.
3. Destabilize the aircraft in the existing open loop flight control system of the host aircraft as measured by classical means.
4. Degrade the flight performance of the host aircraft in excess of 10% as measured by "best range" calculations.
5. Present excessive hazards to the flight crews and support personnel.

2.5 Alterables

The following list contains the alterables associated with the design of the aircraft defense system. Trade-offs in the following areas were made with the underlying objective of meeting the needs and constraints defined in sections 2.3 and 2.4 respectively.

1. Type of missile detection system
2. Type of missile tracking system
3. Types of expendable launching system
4. Type of expendable
5. System operation
6. Aircraft tactics

2.6 Actors

The following is a list of influential players who will ultimately decide the success of the aircraft defense system. Their concerns were considered during this system engineering study.

1. Pilot
2. Missile operator
3. Air Force laboratories
4. System Program Offices
5. Air Combat Command
6. Air Mobility Command
7. Special Operations Command

2.7 Classification Considerations

Along with the standard aspects of the problem defined in sections 2.3 through 2.6, consideration was also given to the security classification of this thesis. There was a conscious effort on the part of the GSE-95D Systems Engineering Team to keep the thesis unclassified. This course of action was taken for two reasons. Based on the purpose of this study, which was primarily a feasibility determination versus a detailed design, it was deemed unnecessary to complicate the study with classified information when it was possible to complete the objective of the thesis with similar unclassified information. Second, all models were designed so as to easily facilitate the substitution of classified for unclassified information. The thesis sponsor, the Electronic Warfare Division of Wright Laboratory, agreed that the final results of this thesis will be useful in establishing a case for further classified research, at which time the models developed will be appropriately modified.

The two primary areas of this thesis which required the substitution of unclassified information for more specific classified information were the detector and tracker characteristics and the threat SAM characteristics. The detector and tracker characteristics of range and bearing accuracy, time-to-detect, mean time between failure, and cost were all based on unclassified information defining existing state-of-the-art detection and tracking systems. This information was provided by the manufacturers of the specific detection and tracking systems and is presented in Tables 4.4 and 4.5.

The real-world SAM used to model the threat SAM in this thesis is the U.S. Army's Stinger missile. The Stinger is a shoulder launched surface to air missile employing passive infra-red homing which has all aspect engagement capability, meaning that it can fire at a target at any angle. It has a length of 1.5 m (5 ft), a weight of 98 N (22 lbf), and a frontal area of 39 cm^2 (6 in^2). Its performance parameters include a ceiling of 3000 m (9840 ft), a maximum range of 5 km (3 miles), and a top speed of 700 m/s (2297 ft/sec) (Vulcan, 1990:208). The velocity profile used in this model is based on unclassified information provided by Wright Laboratory, and is used to characterize missile trajectory during flight (Voegle, 1995). The Stinger constantly spins at a frequency of 15 hertz and arms itself 2 m (6 ft) outside the launch tube (Voegle, 1995). The Stinger has 4 control surfaces and a quartz dome housing the seeker head. The Stinger employs a contact fuse which is activated by a deceleration of 1226 m/s^2 (125 g's), with a delay time of 0.3 microseconds to 0.6 microseconds (Doherty, 1995).

III. Value System Design

The first iteration of the *Value System Design* resulted in the development of a hierarchy chart defining the important characteristics of an optimal active aircraft defense system. The initial characteristics of the hierarchy chart were the result of a group discussion by the Systems Engineering Team. Based on past experiences of the group and on the background research conducted into active aircraft defense systems, the System Engineering Team agreed on the eight characteristics deemed to be the most relevant for the determination of an optimal active aircraft defense system. These characteristics were presented to our sponsor at the Electronic Warfare Division for review and final approval. Figure 3.1 presents the top level hierarchy chart.

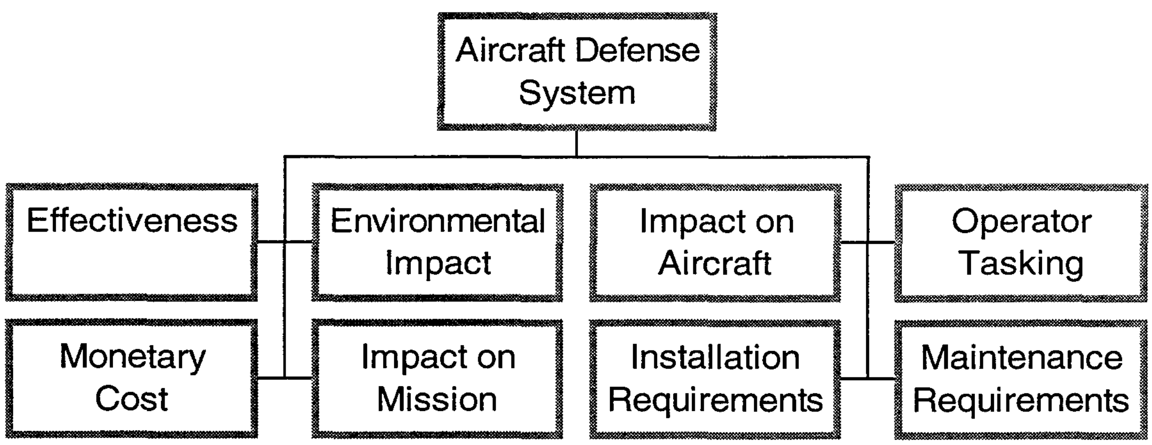


FIGURE 3.1 Top Level Hierarchy Chart

After acceptance of the top level hierarchy chart, each member of the Systems Engineering Group was assigned primary responsibility for one or more of the chart's

characteristics. Each characteristic was then researched and broken down into a detailed hierarchy subchart. Figures 3.2 - 3.9 present these individual hierarchy breakdown charts.

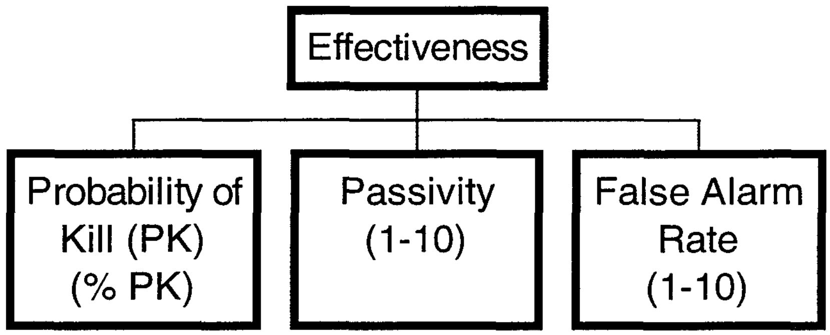


FIGURE 3.2 Effectiveness Chart Breakdown

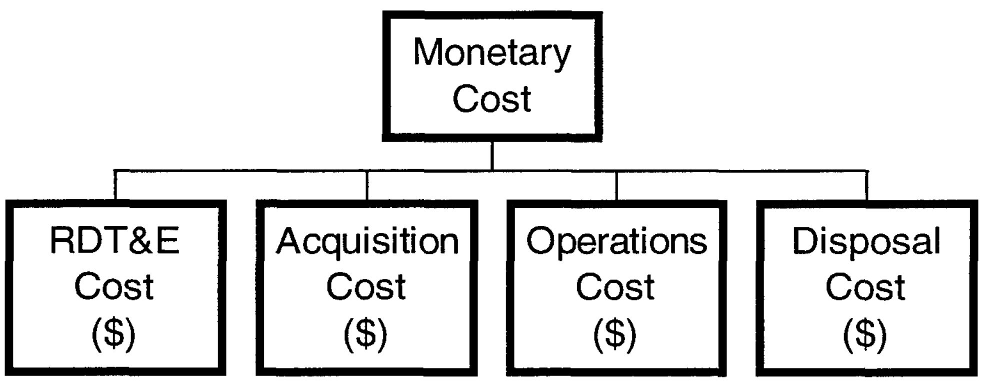


FIGURE 3.3 Monetary Cost Chart Breakdown

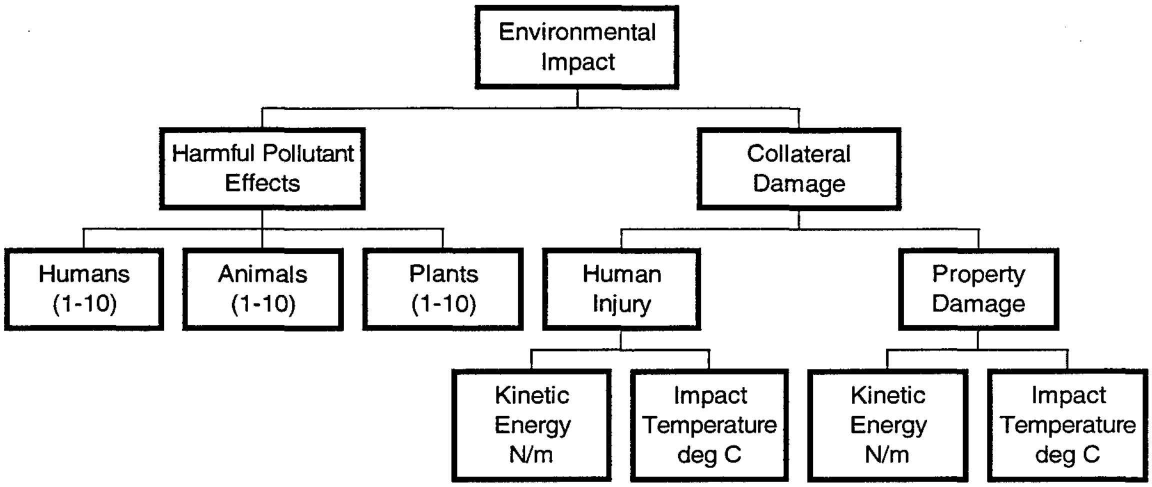


FIGURE 3.4 Environmental Impact Chart Breakdown

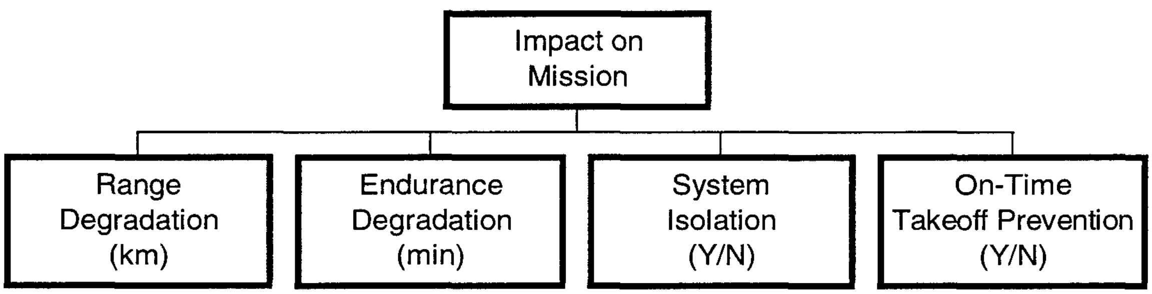


FIGURE 3.5 Impact on Mission Chart Breakdown

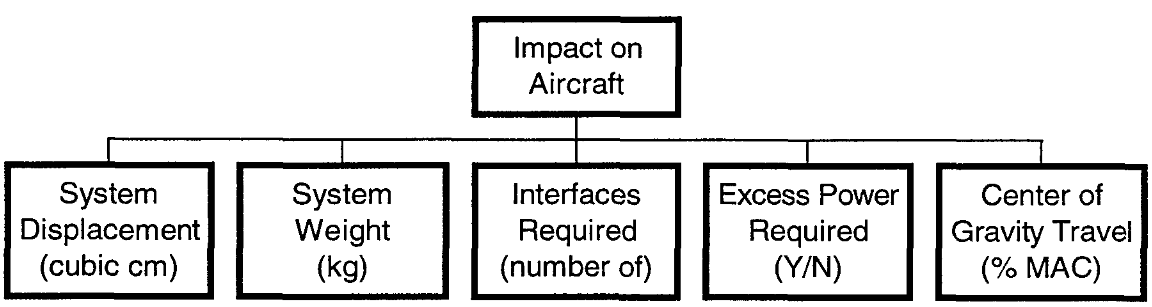


FIGURE 3.6 Impact on Aircraft Chart Breakdown

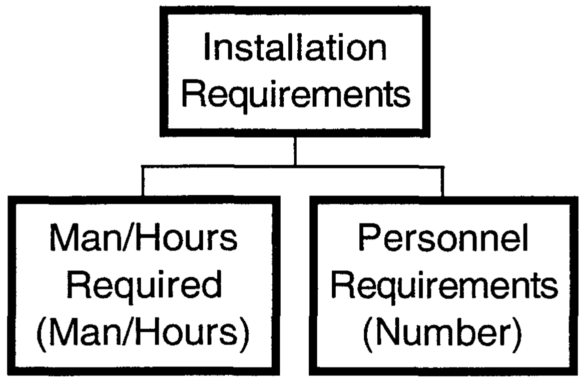


FIGURE 3.7 Installation Requirements Chart Breakdown

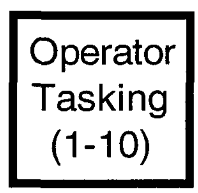


FIGURE 3.8 Operator Tasking Chart Breakdown

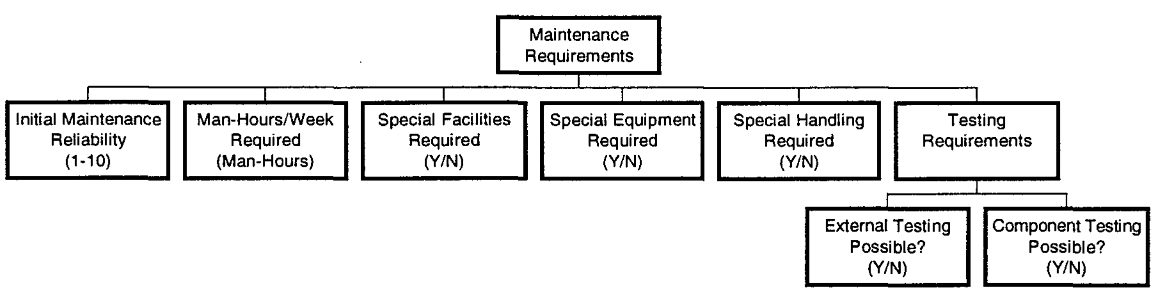


FIGURE 3.9 Maintenance Requirements Chart Breakdown

Effectiveness is a measure of how well an aircraft defense system is able to eliminate the missile threat. From the pilot's point of view, this is definitely the most important characteristic of the system. *Effectiveness* is characterized in terms of three

parameters; probability of kill, passivity, and false alarm rate. Probability of kill defines the effectiveness of the different systems in destroying the missile threat. Passivity rates the level of electromagnetic radiation emmited the aircraft's detection and tracking systems. False alarm rate evaluates how often the aircraft defense system identifies a false threat. Note that based on a lack of any concrete information, it is assumed that the reliablitiy of the expendable's operation is considered perfect and does not affect the effectiveness of the aircraft defense system. In other words, the effectiveness of an aircraft defense system is not based on whether or not the expendable will operate as expected. It is assumed that all candidate expendables will operate as intended. Clearly this is a simplifying assumption, but if one considers that the same level of knowledge was known about all expendable designs, at best, the probability of a particular expendable not operating properly would be the same probability of all other expendables not operating properly. Since this thesis presents a relative comparison among all candidate systems, the reliability of each aircraft defense would evenly affect the evaluation of each system, and would have the same effect as simply assuming each system works perfectly. *Environmental Impact* defines how the aircraft defense system will adversely affect humans, animals, and plant life. Environmental safety is a growing concern of all new weapons systems developed by the Air Force. The impact area and terminal velocities of the deployed expendables are used to calculate the amount of kinetic energy the expendables impart on the earth. This energy, combined with the temperature at impact, help determine the potential for damage to humans and property from the falling deployed expendable. *Impact on Aircraft* defines how much of the

aircraft's excess resources such as surplus space (volume), load carrying capability, and electrical power are consumed by the aircraft defense system. If the system requires excessive amounts of a certain type of resource, it could seriously degrade the flexibility of the aircraft, and may not be worth installing. *Operator Tasking* refers to how much time and energy must be expended by the flight crew in order to operate this aircraft defense system. If the system consumes large amounts of the flight crew's precious time and energy, it may be considered infeasible. *Monetary Cost* refers to the entire life cycle cost of the system, from initial requirements definition to system disposal. Clearly, the greater the life cycle cost, the lower the utility of the aircraft defense system. *Impact on Mission* is defined in terms of performance degradation such as reductions in range and endurance resulting from the aircraft defense system. Excessive performance degradation would significantly reduce the utility of the aircraft defense system. *Installation Requirements* characterize the amount of effort required to modify the aircraft and install the aircraft defense system. Even if a system is effective and inexpensive, for example, if it is takes a great deal of time and personnel to install it, the system may not be considered worth the effort. The Air Force places an important emphasis on the *Maintenance Requirements* of new weapons systems. The ease of maintenance is of primary importance to effective day-to-day operation of the aircraft. If the aircraft spends most of its life on the ground in order to perform maintenance on the aircraft defense system, there may not be a need for a defense system to protect the aircraft for the short period of time that it is in the air.

The hierarchy chart was reevaluated during Iterations Two and Three. After review, it was determined the initial chart sufficiently defined the important characteristics of an active aircraft defense system. Further refinement is probably not warranted as both background research and the expertise of the sponsor determined the chart to be accurate. The largest area for improvement for the chart comes from getting more and more reliable data. Obviously the more reliable and accurate the data evaluated though the hierarchy chart, the better the results.

IV. System Synthesis

Over 4700 possible aircraft defense systems were defined during the first iteration of the System Engineering Process. From this large solution set, the number of possible aircraft defense systems were narrowed during the next two iterations . Iteration Two resulted in 120 candidate aircraft defense systems, which, for modeling purposes, were aggregated to 41 defense systems. Finally, Iteration Three narrowed the solution set to two feasible aircraft defense system. This chapter describes the candidate aircraft defense systems considered during each iteration.

4.1 Iteration One Candidate Systems

The aircraft defense system was divided into the following four subsystems.

1. DETECTOR - Detects a hostile missile inbound to the aircraft
2. TRACKER - Tracks the hostile missile as it approaches the aircraft
3. LAUNCHER - Launches the expendable from the aircraft, toward the missile
4. EXPENDABLE - Eliminates the missile threat

During Iteration One, a morphological approach was used to define all possible alternatives for these four subsystems. A brainstorming session produced the following subsystem alternatives presented in Table 4.1.

TABLE 4.1 Iteration One Subsystem Alternatives

DETECTION	TRACKING	LAUNCHER	EXPENDABLE
Pulse Doppler	Pulse Doppler	Combustible	Anti-Missile Missile (AMM)
Ultra-Violet (UV)	Ultra-Violet (UV)	Explosive	Bullet(s)
Infra-Red (IR)	Infra-Red (IR)	Gravity	Net
LASER	LASER	Springs	Air Cage
Human Eyes	Human Eyes	Towing System	Paint
T.V. Imaging	T.V. Imaging	Drogue Chute	Shot
Sonar	Sonar		Pilot
	None		Flares
			Chaff
			Foam
			Air Pulse
			LASER
			Balloon
			Grenade

4.2 Iteration Two Solution Set

This initial list identified 4704 potential aircraft defense systems. The potential solution set was narrowed during Iteration Two by identifying subsystems alternatives that were infeasible, completely dominated by other alternatives, or outside the technological scope of this thesis. Each subsystem was evaluated individually as discussed in sections 4.2.1 through 4.2.4.

4.2.1 Detector. The detector must be able to distinguish a launched missile from other ground clutter or heat sources with reasonable accuracy. Since the scenario of the attack is during the takeoff and climb-out phases, the detector must be able to quickly scan a given area. The LASER detector was eliminated based on its inability to quickly scan a wide area. Sonar was likewise removed due to its inability to adequately filter out audio noise and reliably identify an inbound missile. TV imaging was eliminated because

of the need for the system to work at night and during bad weather. Human eyes were eliminated because of the inaccuracies involved in working in poor weather as well as long reaction times. The feasible detector systems remaining were IR, UV, and Pulse Doppler.

4.2.2 Tracker. The tracker must be able to quickly track the incoming missile and ascertain information regarding its range and bearing. Sonar and Human Eyes were eliminated as possible tracker alternatives because of their inability to quickly process required information. TV imaging was eliminated because of the need to operate the system at night and in bad weather. The remaining alternatives for the tracking subsystem were IR, UV, Pulse Doppler, LASER, and None (no tracker). The use of no tracker or the "None" alternative was feasible because the detector has some inherent tracking capabilities that may be sufficient for the solution, therefore not requiring a tracker.

4.2.3 Launcher. The Launcher subsystem must be able to propel an expendable away from the aircraft to a position favorable for intercepting the incoming missile. In order to help narrow subsystem alternatives, launchers were divided into two groups, chemical and mechanical launchers. Chemical launchers were further subdivided into those launchers that propel an expendable via the overpressure of a chemical explosion (explosively launched such as a bullet) and those that propel the expendable by creating a sustained thrust via the combustion of a propellant (self propelled such as a missile). In contrast to chemical launchers, mechanical launchers propel the expendable from the

aircraft without an explosion or the burning of a chemical. The propulsive force of these launchers can, for example, be created by springs, gravity, or drogue chutes.

The "Towing" system was eliminated as a launcher because its operation is inherently slow and unrealistic in aircraft operations near the ground. Drogue chutes were eliminated due to their inability to launch an expendable forward of the aircraft. Gravity and springs were eliminated as the necessity for quick acceleration forces prevent them from practically being applied to an aircraft platform. Consequently, the only types of launchers considered were explosive and combustible launchers.

4.2.4 Expendable. The narrowing of the expendable solution set was accomplished in two phases. The first phase determines which kill method is best suited for the given scenario. The second phase involves defining those expendable designs which are feasible and "best" suited to the chosen kill method(s).

4.2.4.1 Feasible Kill Methods. The following list presents the three methods by which an expendable defeats the missile threat.

1. Blind the missile - cover the missile seeker head so that the missile cannot track the aircraft
2. Deflect the missile - impart force on the missile such that the missile is forced outside the aircraft's lethal radius, or is put into an unstable state, i.e. it tumbles
3. Destroy the missile - impact the missile with sufficient mass such that the missile rapidly decelerates and destroys itself through premature detonation, or hit the missile with sufficient force to break it up.

Each of these three alternative methods of eliminating the missile threat were researched. This section presents the results of this research which explains why blinding

and deflecting the missile are impractical, and why destroying the missile appears to be the most effective method of eliminating the missile threat.

The first method considered for eliminating the missile threat is that of blinding the missile. The missile threat, defined in section 2.6, has a seeker head with a frontal area of 38.7 cm^2 (6 in^2). In order to blind the missile, a substance must sufficiently cover this area such that the seeker can not track the aircraft. The seeker itself is a very sensitive instrument. It is capable of tracking very small amounts of infra-red radiation. Even if 99.9% of its optical casing is obscured, the seeker is still capable of tracking an aircraft (Voegle: 1995). As a result, any instrument used to blind the missile must cover over 99.9% of the seeker head in order for it to be effective. In conjunction with the coverage requirement, the expendable must intercept the missile at a sufficient distance such that the missile is not already on a collision course with the aircraft. If a missile loses its "lock" on the aircraft, it will continue toward the aircraft's last known position and still possibly hit it. This required an intercept at a greater distance from the aircraft in order to "blind" the missile sufficiently early to prevent reacquisition.

The various alternatives researched for blinding the missile include liquid, gel, and tarp-like expendables, all of which are intended to cover the seeker head. Based on the following reasoning, it was concluded that blinding the missile was not feasible. The liquid required an excessive volume to guarantee sufficient seeker coverage. Several gallons of liquid would have to be deployed for an engagement. Liquids tend to bead when released in the atmosphere (Burggraf, 1995). Therefore any type of foam, jelly, or liquid would have to be deployed in sufficient amounts such that the dispersion of beads

would guarantee over 99.9% coverage of the missile seeker head at a distance of 150 m (500 ft) from the aircraft. The tarp or cloth cover would have to be deployed such that the cover would adhere to the seeker head upon contact as well as block over 99.9% of the aircraft's heat emissions. The tarp offers the best blinding mechanism, but it would, like the foam and paint, have to intercept the missile at a missile-expendable slant range of 150m (500 ft). In summary, blinding the missile is considered infeasible due to the excessive amount of liquid or gel that would have to be carried aboard the aircraft (primarily a weight and balance problem) as well as the overly stringent requirement of having to cover over 99.9% of the missile seeker head at a range of 150m (500ft) in order for the expendable to be effective.

The second method considered for eliminating the missile threat was that of deflection. In order for this kill mechanism to be effective, the expendable would have to impact the missile with sufficient force and at the correct angle in order to alter the missile's trajectory outside the lethal radius of 30m (100 ft) from the aircraft. The closer the missile is to the aircraft, the more force would be required to deflect the incoming missile. An ideal intercept using the deflection method would impart a force on the missile as far forward or as far aft of the missile's center of gravity as possible. The force would either have to be constant, which would entail the expendable attaching itself to the missile in order to cause a weight and balance problem, or it would have to impart an instantaneous force of sufficient magnitude to cause a tumbling effect. Due to the speed at which the missile is traveling, the missile has a great deal of momentum. Based on this momentum, it is calculated that the expendable must intercept the missile at an aircraft-

missile slant range greater than 150m (500 ft) in order to deflect the missile. These calculations are presented in Appendix A, Calculation 1.

The deflection method was deemed infeasible based on the following requirements. The extreme range at which an expendable-missile intercept must occur, 150m (500 ft), in order to deflect the missile presented a difficult tracking, launch, and intercept problem due to the high degree of accuracy required for the intercept. Similarly, the time required for the expendable to travel the minimum distance was considered to be prohibitively long, on the order of 0.75 seconds. Based on the required high degree of tracking, launch, and intercept accuracy as well as time constraints, deflecting the missile to eliminate its threat was considered infeasibile.

The third method considered for eliminating the missile threat was that of destroying the missile. The missile can be forced to destroy itself through premature triggering of the missile fuse, or it can be blown or cut up by the overpressure and/or shrapnel resulting from an explosion. In order to initiate premature detonation of a missile employing a contact fuse, the expendable must impart sufficient force, 11,000 N (2500 lbf), on the missile's seeker head. Appendix A, Calculation 2 presents the calculation of this force requirement. In order to blow or cut up the missile, the expendable would need only attain a certain relative slant range, based on the type of explosive, in order to ensure the resulting overpressure and/or shrapnel would destroy the missile.

The destruction method was considered feasible for removing the missile threat based on the following advantages. One advantage of the destruction method was that the

missile's momentum could be used against itself. Given the missile's high velocity, only a small amount of mass placed in front of the missile would be required to trigger the missile's contact fuse. A second advantage existed in regard to overall time requirements. Since the objective of the intercept was to destroy the missile, the intercept can take place at any range greater than 30m (100 ft) from the aircraft. This means that the tracking system will have more time (more than if the blinding or deflection methods are used) after missile detection to calculate missile range and velocity and, subsequently, launch the expendable. Based on these advantages and the abundant flexibility afforded by this kill mechanism, missile destruction was considered the only feasible method of removing the missile threat.

4.2.4.2 Feasible Expendable Designs. Based on the destruction method of defeating the missile, the feasibility of each of the candidate expendable designs defined in Table 4.1 was evaluated. The expendable must be able to intercept a missile and effectively remove it as a threat to the aircraft. From the possible expendable alternatives defined in Table 4.1, the following candidate expendables were determined to be synonymous, and were subsequently redefined.

1. Shot and Bullet ≡ Bullet
2. Balloon and Aircage ≡ Inflatables
3. Air-pulse and Grenade ≡ Grenade

The alternative of using the pilot as an expendable is eliminated based on the determination that the crew members were not considered sufficiently expendable to warrant jettisoning them at incoming missiles. Certain individuals continue to debate this decision. A LASER device was eliminated because the technology does not currently

exist in order to design a LASER sufficiently compact and powerful. Chaff and flares were eliminated based on their inability to provide a sufficient, coherent area of coverage. Foam and paint were eliminated due to the fact they are only considered feasible expendables in terms of blinding the missile. The remaining alternatives were Anti-Missile Missile (AMM), Bullet, Net, Inflatables, and Grenades.

4.2.5 Iteration Two Candidate Systems. The solution set was reduced from 4704 potential solution systems to 120. The remaining subsystem were presented in Table 4.2

Table 4.2 Initial Iteration Two Subsystem Alternatives

DETECTION	TRACKING	LAUNCHER	EXPENDABLE
Pulse Doppler	Pulse Doppler	Explosive	Anti-Missile Missile (AMM)
IR	None	Combustible	Bullet(s)
UV	Laser		Net
	None		Inflatables
			Grenade

4.3 Iteration Two Solution Set Modifications

For practicality reasons, the following three modifications were made to the solution sets presented in Table 4.2 in order to define solutions which could be evaluated. First, the measurables defined in the *Value System* for the expendable alternative of an AMM were taken directly from an existing prototype system developed by TRW™ called the Aircraft Close-In Defense System (ACIDS) (Stoddard, 1995). Second, both detection and tracking systems were limited to existing systems. Third, all of the remaining expendables used an explosive launcher except the AMM which uses a combustible launcher.

Along with these three modifications, two other improvements were also made to the Iteration Two solution set. First, two separate alternative net designs were developed during this iteration. Second, a fifth subdivision of the aircraft defense system was defined (to go along with the detection, tracking, launcher, and expendable subdivisions already defined) as the option of launching single or multiple expendables. These additions and modifications are further described in sections 4.3.1 through 4.3.5 along with detailed descriptions of the resulting Iteration Two candidate subsystems.

4.3.1 ACIDS. The AMM was modeled after the TRW™ ACIDS which was a guided, self-propelled missile that is designed to detonate in close proximity to the threat SAM. The measureables quantifying the characteristics specified in the *Value System* for the AMM were taken directly from ACIDS's performance characteristics defined by TRW™ (Stoddard). By definition, using TRW's™ ACIDS's performance parameters dictates that the detection system, tracking system, expendable, and launcher on which the AMM system was based are the same as those employed in the ACIDS.

The ACIDS missile weighs approximately 66.75 N (15 lbf), with a 22.25 N (5 lbf) warhead. The warhead was packed with explosives and was scored such that shrapnel will spread in the desired direction upon detonation. The ACIDS launch system imparts a 981 m/s^2 (100 g) acceleration on the missile. Up to 8 missiles can be loaded into a single ACIDS launch pod. ACIDS was designed to update the location of the threat missile via telemetry from the tracking system on-board the aircraft. The approach velocity of the ACIDS missile to the threat missile is approximately Mach 2. When the ACIDS missile is about 1 m (3 ft to 4 ft) from the threat missile, a proximity fuse causes detonation of the

ACIDS missile warhead. The explosion was designed to destroy the threat SAM within a 1.2 m (4 ft) radius which equates to a coverage area of approximately 4 m^2 (50 ft^2) (Stoddard, 1995).

4.3.2 Detector and Tracker Composites. Candidate detection and tracking systems were defined in terms of existing, primarily state-of-the-art systems. Existing systems currently span the range of cost and performance. Detection and tracking systems currently exist which range from relatively inexpensive and relatively inaccurate systems to expensive systems which provide very accurate range and bearing measurements. For the purposes of this study, the GSE-95D Systems Engineering Team was only concerned with particular characteristics of these systems such as range and bearing accuracy, monetary cost, and mean time between failure (MTBF). As a result, current detection and tracking systems were grouped together based on range and bearing accuracy, monetary cost, and MTBF, and composites of these characteristics were then used to define generic detection and tracking systems for this thesis. Sections 4.3.2.1 and 4.3.2.2 define these composite systems.

It would have been possible for the GSE-95D Systems Engineering Team to simply choose an existing detection and/or tracking system. With the availability of systems, all ranging in cost and performance as described in the previous paragraph, the GSE-95D Systems Engineering Team was confident that a suitable system would be found. The Team decided to develop composite systems because we did not want this thesis to be used as a recommendation for any one particular detection and/or tracking system. Instead, the GSE-95D Systems Engieering Team wanted to simply concentrate

on those characteristics which define the detection and tracking systems. It is these characteristics and not the particular system to which these characteristics are tied which are important.

4.3.2.1 Detector. The detector is a composite of the AAR-47, a UV system, and the ALQ-156, a pulse-Doppler system. The composite is a low cost quadrant detector with no ranging capability. Table 4.3 presents the specific characteristics of the existing systems and the resulting characteristics of the composite system. Data for the existing system come directly from the system's manufacturer.

TABLE 4.3 Iteration Two Detector Composite #1 Specifications

System	Cost ($1000)	Range Accuracy (± m)	Bearing Accuracy (± deg)	MTBF (hrs)
AAR-47	80	549 (1.5 s time-to-target)*	Quadrant	1677
ALQ-156	100	549 (1.5 s time-to-target)*	Quadrant	1677
Composite	100	None	Quadrant	1677

* Based on an average aircraft - missile closure velocity of 366 m/s

The Composite #1 range accuracy was degraged from 549 m to "none" based on the GSE-95D System Engineering Team's opinion that for the particular application with which this composite detector was to be used, having a range accuracy that exceeded 500 meters was effectively useless. As a result, when this system was modeled in the Aircraft-Missile-Expendable simulation which is described in Chapter V, it was done so without range determination capability.

4.3.2.2 Tracker. Three separate composite tracking systems are developed during Iteration Two. The composite tracking systems are grouped into three categories based on the varying degrees of range and bearing accuracy. Although it is defined as a composite, tracker Composite #1 is actually defined solely by a worst-case

scenario (range and bearing) of the AAR-54, a UV system. In other words, if the expected range accuracy of the AAR-54 is ±800 m to ±1200 m, the tracker Composite #1 accuracy would be defined as ±1200 m. Tracker Composite #2 is a mid-level tracker which is a composite of an average AAR-54 and an AAR-44, IR system. Tracker Composite #3 is a state-of-the-art tracker developed as a composite of Northrop's Directed Energy Counter Measures (DIRCM)™ system which uses the AAR-54 as a detector and a directed energy system, similar to a LASER, as a tracker, and the TRW™ system, an aircraft-mounted Millimeter Microwave (MMW) Frequency Modulated/Continuous Wave (FM/CW) radar system with a passive AAR-47 cueing/detection system. Tracker Composite #3 more closely resembles the TRW™ system than the DIRCM system. DIRCM is included in the definition of tracker Composite #3 primarily due to the similarity in bearing accuracy between it and the TRW™ system. Table 4.4 through 4.6 presents the specific characteristics of the existing tracking system(s) and the resulting characteristics of the corresponding composite system. Data for the existing state-of-the-art tracking systems come directly from the system's manufacturer.

TABLE 4.4 Iteration Two Tracker Composite #1 Specifications

System	Cost ($1000)	Range Accuracy (± m)	Bearing Accuracy (± deg)	MTBF (hrs)
AAR-54	150	366 (1.0 s time-to-target)*	6	3500
Composite	150	366	6	3500

* Based on an average aircraft - missile closure velocity of 366 m/s

TABLE 4.5 Iteration Two Tracker Composite #2 Specifications

System	Cost ($1000)	Range Accuracy (± m)	Bearing Accuracy (± deg)	MTBF (hrs)
AAR-44	350	274 (< 1.0 s time-to-target)*	1	300
AAR-54	150	274 (< 1.0 s time-to-target)*	1	3500
Composite	250	274	1	350

* Based on an average aircraft - missile closure velocity of 366 m/s

TABLE 4.6 Iteration Two Tracker Composite #3 Specifications

System	Cost ($1000)	Range Accuracy (± m)	Bearing Accuracy (± deg)	MTBF (hrs)
DIRCM **	Unknown	274 (<1.0 s time-to-target)*	0.05	2000
TRW ***	1000	0.5	0.05	1000
Composite	950	0.5	0.05	1666

* Based on an average aircraft - missile closure velocity of 366 m/s
** Northrop's Directed Infrared Counter Measures system which uses AAR-54 as a detector and a directed energy tracker
*** TRW MMW FM/CW Radar System

4.3.3 Launcher. Excluding the AMM, all other expendables are launched by an explosive launcher during Iteration Two. This decision was made based on the simplicity of the explosive relative to the combustible launcher. Simpler systems were generally less expensive, easier to maintain, an have higher MTBFs. If Iteration Three analysis shows that the expendables were not reaching the missile fast enough, a combustible launch system will be considered for each candidate expendable.

4.3.3.1 Explosive. Two types of Explosive launchers were used in Iteration Two. The first type of explosive launcher was used solely by the Bullet expendable. The Bullet candidate expendable was launched from a Vulcan 20 mm six barrel gun. The gun is capable of firing rounds from 1000 rounds per minute to 3000 rounds per minute with a dispersion of 12 milliradians. The second type of explosive launcher was used by all remaining expendables in Iteration Two. These expendables are

launched from a separate explosive launch system based on the ALE-17 flare bucket. This bucket launch system was coupled with the ALE 47 launch control system that is currently used on the U.S. Air Force F-15 aircraft and AC-130/MC-130 aircraft (Brunhelder, 1995). The bucket has a square cross section and dimensions of 19.1 cm (7.5 in) by 20.6 cm (8.1 in) by 14.6 cm (5.8 in) resulting in a volume of 5744.5 cm^3 (352.4 in^3) (Brunhelder, 1995). The ALE-17 bucket is attached to an expendable stand. The expendable stand resembles a large metal "Lazy Susan" with a "U" bracket in the center required to mount the ALE-17 bucket. The mounted bucket is capable of rotating 360 degrees. The "Lazy Susan", which rotates on MIL STD "Aircraft Grade" ball-bearings, is driven by a DC electric motor which provides rotation rates of approximately 360° per second. The exact rotation rate was determined by the amperage and gearing of the electric motor. The limiting factor on the rotation rate was the precision of the ball bearings, which determines the friction. The launcher "Lazy Susan" has an 89 cm (35 in) circular aluminum base which weights 267 N (60 lbf). The rotating plate is a smaller aluminum disk having a radius of 32 cm (12.6 in). The plates are separated by 3 mm (.12 in) bearings placed on a machined bearing track and are joined with a 5.1 cm (2 in) carriage bolt in the center of the plates with the U bracket for the ALE 17 bucket centered over the head of the carriage bolt. A diagram of the ALE 17 bucket is presented in Figure 4.1. Figure 4.2 presents a diagram of the ALE 17 bucket attached to the "Lazy Susan" launch assembly.

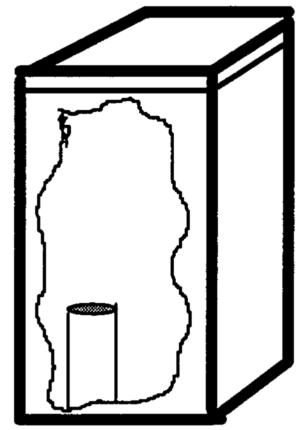


FIGURE 4.1 ALE 17 Flare Bucket

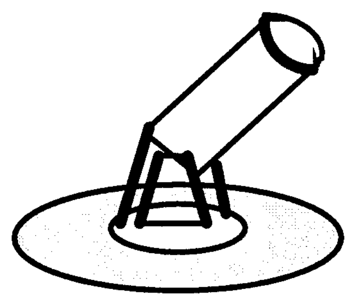


FIGURE 4.2 Launcher

Currently charged flares are placed in the bucket, standing on end. The base of a flare is much like a bullet with a charge to propel it from the bucket. When an electric firing clip located at the bottom of the bucket is energized, the corresponding flare ignites and is propelled from the bucket like a bullet from a rifle (Brunhelder, 1995). Iteration Two candidate expendables were launched in the same manner. The expendable was loaded on a charge, and when the charge is ignited, the expendable is propelled from the bucket. The maximum allowable explosive charge, based on structural limitations of the bucket, results in an expendable muzzle velocity of 200 m/s (700 ft/s) (Brunhelder, 1995).

4.3.3.2 Combustible. The combustible launcher used for this analysis was the launcher used by the TRW™ AMM system. Since this was the only candidate expendable to use this launcher, no modifications were made.

4.3.4 Expendable. Preliminary designs for the Bullet, Net, Inflatable, and Grenade candidate expendables defined in Table 4.2 are presented in this section. Two nets, one made of Spectra™ and the other made of Detonation Chord™, were developed during Iteration Two. Excluding the Bullet, all other expendables are launched from the aircraft encased in a spherical container. Once the container reaches a distance of 30 m (100 ft) from the aircraft, a shaped charge explosive is detonated by a timing fuse within the sphere which deploys the expendable. Based on geometrical constraints of the flare bucket, the sphere is defined to be 15.24 cm (6 in) in diameter.

4.3.4.1 Bullets. The Bullet is a 20 mm round which has a cross section area of 3.14 cm^2 (0.487 in^2) and weighs 0.979 N (0.22 lbf). Assuming the burst limiting device on the Vulcan 20 mm gun is set at 100 rounds per second, at a distance of 30 m (100 ft) the barrage of Bullets covers an area of 4.52 ft^2 (Vulcan, 1989:208). The 20 mm rounds eliminate the missile threat by penetrating the missile casing and causing premature detonation. A detailed description of the Iteration Two Bullet expendable design is presented in Appendix A, Calculation 3.

4.3.4.2 Spec-Net. The Spec-Net is a 14 sided polygon shaped net made of Spectra™. Spectra™, a modified polyethylene, is similar to Kevlar™ (Mangolds, 1995). Spectra™ is used for this net based on its extremely high tensile strength of 129,270 N/cm^2 (187,500 lbf/in^2) (Mangolds, 1995). Weights are attached to the

perimeter of the net which facilitate the net's symmetrical deployment. Following deployment, the momentum of the weights help to keep the net expanded. The net's mesh size is approximately 22.5 cm^2 (3.5 in^2), with a Spectra™ material diameter of .12 cm (0.048 in). The entire Spec-Net covers an area of 94.57 m^2 (1017.9 ft^2).

The Spec-Net destroys the threat missile by impacting the missile and decreasing its velocity quickly enough that the missile's fuse detonates. A positive aspect of the Spec-Net was that if the perimeter weights are equally balanced, the net will "fly" symmetrically (net's velocity vector is perpendicular to the net's face) for a period of between 2.0 seconds and 5.0 seconds (Mangolds, 1995). The determination of the Spec-Nets parameters for Iteration Two are displayed in Appendix A Calculation 4. Figure 4.3 shows the basic geometry of the Spec-Net.

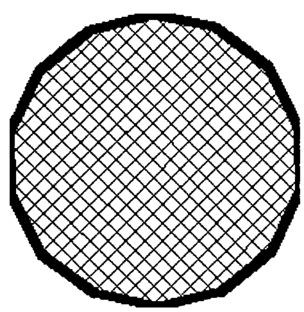


FIGURE 4.3 Net Geometry

4.3.4.3 Det-Net. The Det-Net is also a 14 sided polygon net, but instead of Spectra™, it is made of Detonation Chord™. Detonation Chord™ is an explosive chord that detonates when it is sheared (Hoffman, 1995). Like the Spec-Net, the Det-Net has weights around its perimeter in order to improve flight characteristics. The net's mesh size is approximately 22.5 cm^2 (3.5 in^2), with a Detonation Chord™ outside

diameter of 0.361 cm (0.142 in). The entire Det-Net covers an area of 65.7 m^2 (706.86 ft^2). Detonation Chord™ is not as flexible as Spectra™. Consequently, the Det-Net has packaging densities ranging from only 63% to 84%.

The Det-Net works similar to the Spec-Net. The threat missile impacts the Det-Net and shears the Detonation Chord™. The detonation chord has a high explosive propagation velocity ranging from 5486.4 m/s to 1.22 m/s (18,000 ft/s to 4 ft/s) which causes the entire net to detonate very quickly (Mangolds, 1995). See Appendix A, Calculation 5 for Detonation Chord™ propagation calculations. The resulting explosion slices through the missile and destroys it. The Iteration Two calculations for the Det-Net are displayed in Appendix A, Calculation 6.

4.3.4.4 Inflatables. There were several Inflatable designs. The simplest design was the Balloon. This expendable is launched from the aircraft in a non-inflated state. Upon reaching the intercept location, the Balloon is released from the casing and inflated with high pressure CO_2 gas. The Balloon has the advantage of a constant cross sectional area regardless of orientation. The Balloon also has a slow descent rate, ensuring a higher probability of missile impact. The disadvantage of this design was the weight associated with compressed CO_2. Over 65% of the total expendable weight is composed of compressed CO_2 and CO_2 canisters. This is weight that could be used for more material which in turn would provide a larger missile intercept area. Figure 4.4 shows the simple shape of the ballon expendable and the attached CO_2 canister.

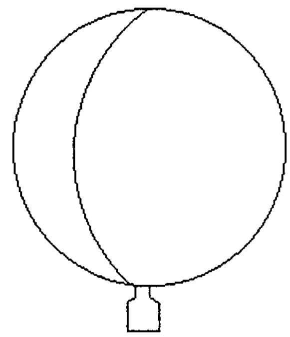


FIGURE 4.4 Balloon expendable

A second type of Inflatable expendable design was the Air Cage. The Air Cage is similar to the Balloon in that it is launched un-inflated and then, upon reaching the missile intercept location, filled with CO_2 gas. The distinction between the Balloon and the Air Cage is that only the supporting ribs of the Air Cage are filed with CO_2. The shape of the Air Cage is similar to a floating prison cell in which the bars are inflated with CO_2 gas and material is stretched between the bars. The Air Cage has all the advantages of the Weather Balloon but requires 30% less CO_2 gas. Figure 4.5 depicts the overall shape of the Air Cage. Individual canisters are located at the base of every rib, providing CO_2 gas for inflation and weight for stability in flight.

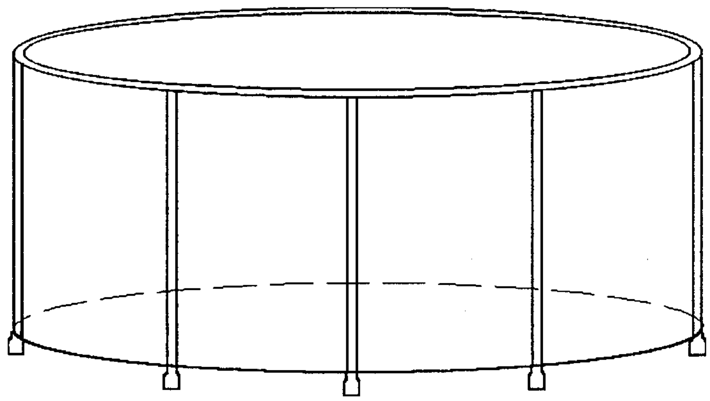


FIGURE 4.5 Air Cage Design

Finally, a third type of Inflatable expendable design was the Air Bag. The Air Bag shape is similar to a standard garbage bag modified with weights attached to the perimeter of the bag's open end. The Air Bag is made of F-111 rip stop nylon, the same material used in parachutes. Rip stop nylon is light and extremely shear resistant. To deploy the Air Bag, the spherical container holding the expendable is launched from the aircraft. Once at the intercept point, the Air Bag is deployed via the detonation of the sphere. The weights rapidly spread apart thereby opening a channel for outside air to inflate the bag. Once inflated, the weights act as a ballast and orient the bag with the open end facing the ground. This creates a parachute effect which gives the Air Bag a slow descent rate.

The advantages of the Air Bag were the same as other Inflatable expendable designs, slow decent rate and constant cross-sectional area. A third advantage results from the primary design difference between the Air Bag and the other two Inflatable expendable designs. Unlike the first two Inflatable designs, the Air Bag was not hindered by the requirement to carry CO_2 gas in order to inflate. Instead ram air is used to inflate

the Air Bag. The resulting advantage is that the overall surface area of the Air Bag is much larger since the majority of the volume allotted for the Air Bag expendable can be composed of the F-111 rip stop nylon material (a small portion of the volume must be allotted for the weights) instead of CO_2 gas. Figure 4.6 shows the basic geometry of the Air Bag. The thick band around the bottom of the bag represents the perimeter weights required in the Air Bag design.

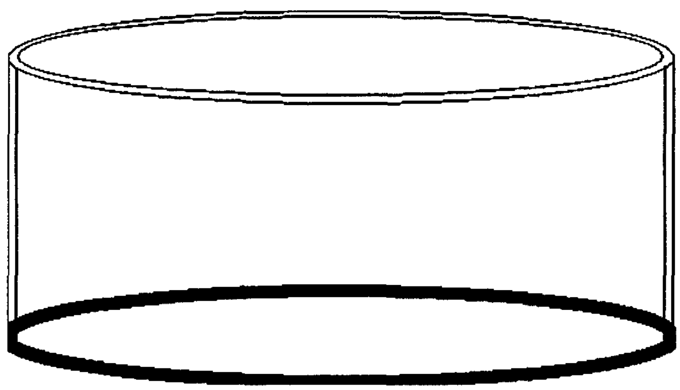


FIGURE 4.6 Air Bag Design

The Air Bag design dominated all other inflatable type expendables in terms of area coverage. As a result, the Air Bag was the only inflatable expendable considered during Iteration Two. The Air Bag had an effective area of coverage of 4.84 m^2 (52.1 ft^2) and weighed 14.50 N (3.26 lbf). Appendix A, Calculation 7 describes the design of the Air Bag for Iteration Two.

4.3.4.5 Grenade. The grenade, or "Cherry Bomb" as it is termed in this thesis, was a warhead packed with RDX™ explosive that detonates at close proximity to the incoming missile threat and shreds the missile with pieces of shrapnel. The spherical

metal casing in which the grenade is housed is scored such that shrapnel will be created by the explosion. The impact of this shrapnel along with the force due to the explosive overpressure result in the disintegration of the missile. The calculations for the Iteration two design of the Cherry Bomb are displayed in Appendix A, Calculation 8.

4.3.5 Multiple Expendables. A variation not considered in the previous Iterations was using multiple expendables. Instead of launching a single expendable at the threat missile, it may be more advantageous to launch multiple salvos. The multiple salvo capability refers to the ability to launch one, two , three, up to seven expendables from the aircraft. The maximum number of seven was based on the limitations of the software used to simulate the trajectory of the multiple expendables. This simulation is explained in section 5.1. It is clear that launching multiple salvos from the aircraft should increase the PK of the system. What is not clear is the overall effect with regard to monetary cost, maintenance, etc. Consequently, the number of expendables launched was considered a variable in the aircraft defense system design for Iteration Three along with the detector, tracker, launcher, and expendable.

4.3.6 Iteration Two Candidate Systems. Table 4.7 presents a summary of the subsystem alternatives developed in Iteration Two. The solution set was reduced to 41 candidate aircraft defense systems, the 40 developed from the alternatives presented in Table 4.7 plus the AMM system.

TABLE 4.7 Iteration Two Subsystem Alternatives

Detection	Tracking	Launcher	Expendable Type	Number of Expendables Launched
Composite #1	Composite #1 Composite #2 Composite #3 None	Explosive	Bullet Spec-Net Det-Net Air Bag Cherry Bomb	Single Multiple

4.4 Iteration Three Solution Set

The performance of the candidate aircraft defense systems defined in Table 4.7 were calculated during Iteration Two. The models used to quantify the performance of these candidate systems are presented in Chapter V. The results of this evaluation are presented in Chapter VI and summarized in Table 4.8.

TABLE 4.8 Iteration Three Subsystem Alternatives

Detection	Tracking	Launcher	Expendable Type	Number of Expendables Launched
Composite #1	Composite #3 Composite #2a	Explosive	Cherry Bomb Spec-Net Det-Net	Single

Table 4.8 presents those subsystems deemed worthy of further study in Iteration Three. The logic behind this decision is presented in Chapter VII.

This section describes the next level of detailed design of those subsystems presented in Table 4.8. First, modifications to tracker Composite #2 resulting in a new tracker, Composite #2a, are discussed. Second, improvements in the range and bearing accuracy values defining tracker Composite #3 are presented. Third, modifications to the container in which the expendables are launched are presented. Fourth, modifications to

the explosive launcher are described. Finally, improvements to the remaining candidate expendable designs are discussed.

4.4.1 Tracker Composite #2a. Along with the Composite #3 tracker which is determined to be the best tracker for all candidate aircraft defense systems in Iteration Two, a modification of tracker Composite #2 is also considered in Iteration Three. This new tracker, Composite #2a, is similar in design to tracker Composite #2. The difference is the addition of a ranging antenna attached to the expendable. This modification results in a range accuracy comparable to Tracker #3. The bearing accuracy remains the same as tracker Composite #2. This modification is made based on information gained from Iteration Two which indicates the immense importance of range information. The fact that the Composite #2a tracker cost approximately the same as tracker Composite #2, and it has range accuracy comparable to tracker Composite #3 are both advantages of this new tracker design.

4.4.2 Tracker Composite #3. Based on further research, more accurate values defining the range and bearing accuracies of Composite Tracker #3 were determined during Iteration Three. The range accuracy increases from 0.5 m to 1.8 m and the bearing accuracy decreases from 0.05° to 0.5°.

4.4.3 Expendable Bullet Canister. Instead of using a spherical container in which to hold the expendables during launch, a bullet-shaped canister was used for Iteration Three. The "Bullet Canister" as it is termed throughout the remainder of this thesis, has a radius of 6.5 cm (2.56 in), a length of 39 cm (15.4 in), and an empty weight of 16.9 N (3.9 lbf) resulting in a volume of 5744 cm^3 (352 in^3), the same volume as the

existing ALE-17 flare bucket. A detailed design of the Bullet Canister is described in Appendix A, Calculation 9. The bullet-shaped design was used in order for the launcher to impart an angular velocity to the canister as it is launched, similar to a bullet launched from a rifle. This rotation spin stabilizes the canister. Spin stabilization increases the probability that the canister is properly oriented when the encased expendable is deployed. Figure 4.7 depicts the Bullet Canister.

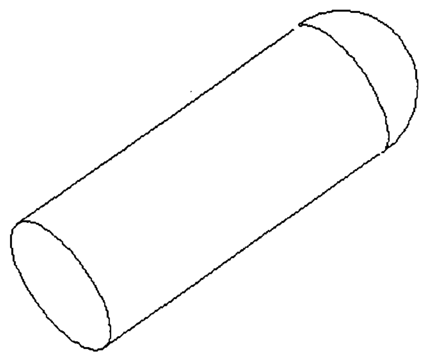


FIGURE 4.7 Bullet Canister

4.4.4 Launcher. The Iteration Three launcher was shaped like a cylinder with interior spiral grooves, similar to a rifle. The launcher has an inside diameter of 13 cm (5.1 in) and a length of 80 cm (31.5 in). As described in section 4.4.3, the Iteration Three launcher, was designed to rotate the Bullet Canister at a rate of 40 radians per second, the average rotation rate of artillery shells, in order to spin stabilize the canister (Bandstra, 1985:2). The muzzle velocity of the bullet canister as it leaves the launcher is 200 m/s (700 ft/s).

4.4.5 Spec-Net. During Iteration Three, the Spec-Net's design is further refined. Detailed calculations to determine the size of the net, the thickness of Spectra™ cord,

and the amount of perimeter weights required for aerodynamic stability are all performed for this design. The net is optimized to destroy a Stinger missile at an average closing impact speed of 1950 m/s (6398 ft/s).

Based on information from the Missile and Space Intelligence Command the Stinger has a contact fuse that requires an acceleration of between 100 and 125 G's in order to detonate. The force required to detonate this missile is calculated in Appendix B, Calculation 2 to be 11,000 N (2472 lbf). The net is designed so that at a minimum of two Spectra™ cords will come in contact with the missile if the missile impacts the Spec-Net. The cords will apply sufficient force on the head of the missile so the missile will detonate prematurely. To aid in the deployment and flight characteristics of the Spec-Net, 30 % of the net's total weight is placed around the outer perimeter. Upon release from the canister, perimeter weights force the net to expand and remain in a symmetric disk shape during flight (Mangolds, 1995). Tungsten weights, chosen for their high density and heat resistance, line the outer ring of the net and provide the necessary concentration of perimeter weights at the minimum volume.

The Spec-Net is designed to fit into the Bullet Canister. The overall weight is 51N (11.5 lbf) and the effective area of coverage is 38 m^2 (409.5 ft^2). Appendix A, Calculation 10 is a detailed breakdown of the design parameters for the Iteration Three Spec-Net.

4.4.6 Det-Net. The Det-Net design was further refined during Iteration Three. Detailed calculations to determine the size of the net, thickness of Detonation Cord™ and the amount of perimeter weights required for aerodynamic stability are all performed for

this design. The net is optimized to destroy a Stinger missile at an average impact speed of 1950 m/s (6398 ft/s).

Tests performed by Foster-Miller Inc. determined that a 1.62 g (25 grain) Detonation Cord™ has the explosive capability to cut a Stinger missile in half. (Hoffman, 1995) The Detonation Cord™ chosen for Iteration Three is a 1.78 g (27.5 grain) cord consisting of a powdered plastic explosive wrapped in a Kevlar™ outer-mesh. The powdered form of the explosive allows the net to be light weight, while the Kevlar™ outer-mesh provides structural integrity. The weight of 1.78 g (27.5 grain) offers a 10 % margin of safety over the minimum 1.62 g (25 grain) chord, thereby increasing the probability that the Det-Net will destroy the missile. To aid in the deployment and flight characteristics of the Det-Net, 30 % of the net's total weight is placed around the outer perimeter. Upon release from the canister, perimeter weights force the net to expand and remain in a symmetric disk shape during flight (Mangolds, 1995). Tungsten weights, chosen for their high density, line the outer ring of the net and provide the necessary concentration of perimeter weights at the minimum volume.

The Det-Net was designed to fit into the Bullet Canister. The overall weight is 47.38 N (10.65 lbf) and the effective area of coverage is 59.17 m^2 (636.39 ft^2). Appendix A, Calculation 11 is a detailed breakdown of the design parameters for the Iteration Three Det-Net.

4.4.7 Cherry Bomb. The Cherry Bomb design was further refined in Iteration Three. During Iteration Two, it was assumed that all of the area inside the radius of the exploding Cherry Bomb would be covered with shrapnel pieces. Therefore the Cherry

Bomb's effective area would be equal to the circle created by the outer radius of the exploding shrapnel pieces as seen in Appendix A, Calculation 12. During Iteration Three, a more detailed analysis was conducted. To ensure a missile cannot slip through the coverage area, the exploding shrapnel pieces had to be spaced such that an area the size of the missile head cannot be placed between the pieces of shrapnel as they fly from the Cherry Bomb.

Based on the new analysis, the effective area of the Cherry Bomb was significantly reduced from the Iteration two area of coverage. The type of explosive RDX™, and the steel shrapnel remain the same. As in Iteration Two, the RDX™explosive is chosen because of its high energy to density ratio. Steel was chosen as shrapnel because it is very hard, and has a high strength to weight ratio.

The Cherry Bomb was designed to fit into the Bullet Canister. The overall weight is 330 N (74 lbf) and the effective area of coverage is 69750 cm^2 (75 ft^2). Appendix A, Calculation 12 presents a detailed breakdown of the design parameters for the Iteration Three Cherry Bomb.

4.5 Final Solution Set

The performance of the candidate aircraft defense systems defined in Table 4.8 were calculated during Iteration Three. The models used to quantify the performance of these candidate systems are presented in Chapter V. The results of this evaluation are presented in Chapter VI and summarized in Table 4.9

TABLE 4.9 Optimal Aircraft Defense Systems

Detection	Tracking	Launcher	Expendable Type	Number of Expendables Launched
Composite #1	Composite #2a	Explosive	Spec-Net Det-Net	Single

Table 4.9 presents those subsystems considered to be the optimal aircraft defense systems based on the evaluation of the candidate aircraft defense systems considered during Iteration Three. The logic behind this decision is presented in Chapter VII.

V. System Modeling

Models developed in Iteration One take the form of defining expected system performance on a 1 to 10 scale. These performance ratings are based on literature research regarding the various aircraft defense system alternatives. More scientific models were developed for each category identified in the *Value System Design* stage during the second iteration of the Systems Engineering Process. These models were further refined in Iteration Three. This chapter discusses the development of each model during Iteration Two and improvements made during Iteration Three. Sample model calculations for a particular aircraft defense system are presented in Appendix B.

5.1 Effectiveness Model

The purpose of this model was to determine how effective each candidate aircraft defense system was at eliminating the threat of a SAM when the C/KC-135 aircraft is in the takeoff and climb-out configurations. The effectiveness of each aircraft defense system was based on three measurables - probability of kill (PK), passivity, and false alarm rate. Presented in this section is a discussions of how each measurable is calculated. Due to its relative complexity, the majority of this discussion encompasses the PK calculation.

5.1.1 Probability of Kill. The PK of the various aircraft defense systems was evaluated via a digital simulation developed by the GSE-95D Systems Engineering Team. The digital simulation, hereafter referred to as the Aircraft - Missile - Expendable (ACME) simulation, was developed using the software packages MATLAB® and

SIMULINK™ (MATLAB® With SIMULINK™, 1995). The top level block diagram of ACME is presented in Figure 5.1 The entire ACME simulation is presented in Volume 2 of this thesis. The primary function of the simulation was to model the dynamics of the C/KC-135 aircraft, the shoulder launched missile, and the candidate expendables designed to defeat the missile. The ACME simulation and the logic on which the PK calculation is based are presented in sections 5.1.1.1 through 5.1.1.4.

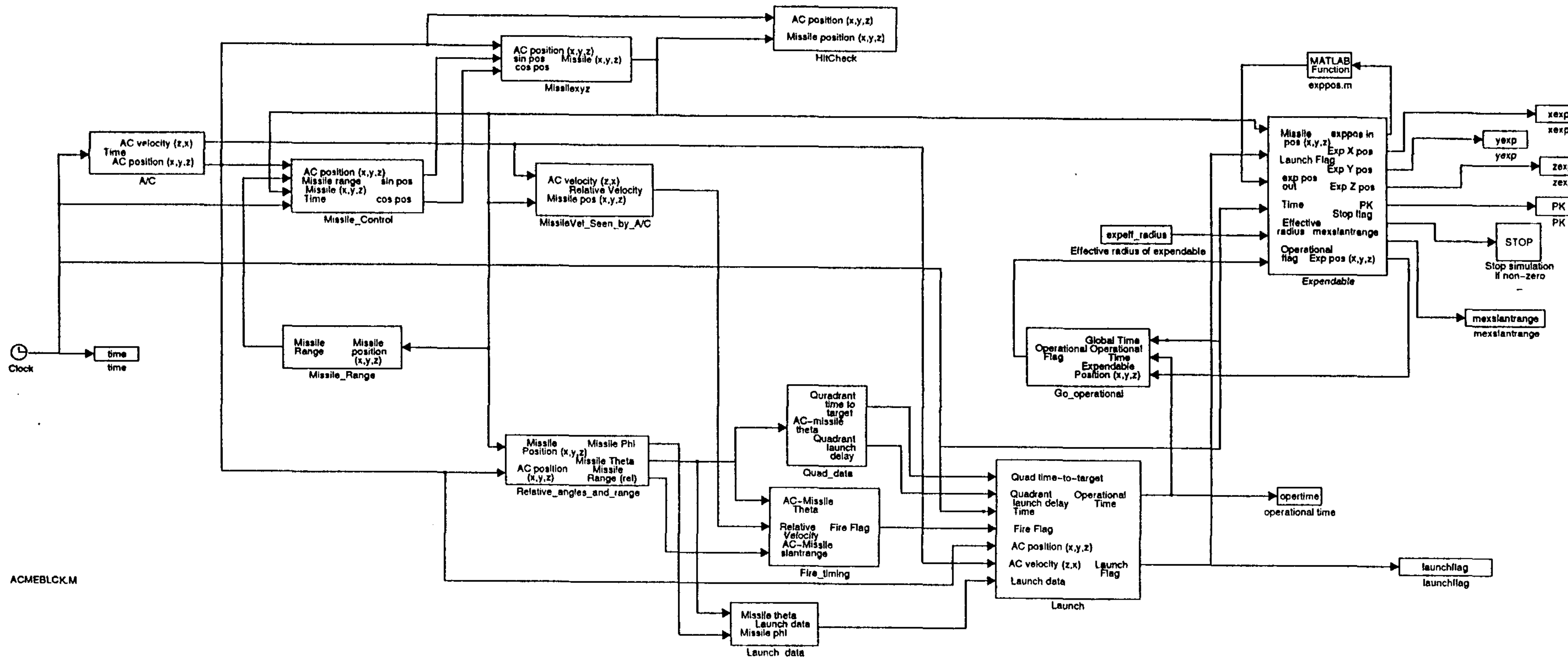


Figure 5.1 ACME Simulation Top Level Block Diagram

5.1.1.1 Aircraft - Missile - Expendable Simulation. The C/KC-135 aircraft was modeled in the ACME simulation as a point mass climbing at a constant velocity of 82.3 m/s (157 KIAS) and a constant climb angle of 2.3°. Since a C/KC-135 performs very limited maneuvering when climbing out after takeoff, a point mass assumption was believed to be a valid simplifying assumption. Similarly, the constant velocity and constant climb angle assumptions were considered valid based on climb-out profiles prescribed in T.O. 1C-135A-1-1, the C/KC-135A flight manual (KC-135A Flight Manual, 1966). The maximum velocity deviation was defined by the flight manual to be 6.18 m/sec (12 KIAS)

The shoulder launched missile in the ACME simulation is modeled as a "generic" missile employing dynamics taken from Surface-Based Air Defense System Analysis by Robert H. M. Macfadzean (Macfadzean, 1992:147). True missile dynamics were not used based on the desire to maintain this thesis as an unclassified document (Stinger dynamics are classified). The missile was assumed to employ Line of Sight (LOS) logic, since LOS is the most common type of logic employed by shoulder launched missiles (Macfadzean, 1992:215). LOS logic dictates that the missile trajectory must null the relative angle between the position vectors of the missile and of the aircraft using the missile launch point as the vertex. The maneuvering of the missile was modeled as an acceleration normal to the flight path of the missile. Although this model did not provide a true description of the missile's trajectory, it was considered accurate enough for digital simulation purposes (Macfadzean, 1992:143). The velocity of the missile in the ACME

simulation during Iteration Two was based on a generic velocity profile for a shoulder launched missile. This profile was later improved in Iterations Three.

As described in section 4.3.4, all expendables are shot from the aircraft encased in a container, excluding the Bullet candidate expendable. When the expendable reaches a desired point in space, it is then deployed from this container. The trajectory of this sphere was determined by numerically integrating second order nonlinear differential equations describing the dynamics of the sphere. Separate equations were developed for the forward (X), lateral (Y), and vertical (Z) directions. Due to symmetry of the container, the forward and lateral equations are the same. The vertical equation was slightly different due to the force of gravity. Calculations of these equations are presented in Appendix A, Calculation 13.

Once a particular expendable is deployed, the dynamics of it will obviously differ from other candidate expendables. Similar to the sphere, the trajectory of each deployed expendable was determined by numerically integrating second order nonlinear differential equations developed from free body diagrams. Separate equations were developed for the forward, lateral, and vertical directions. The forward and lateral equations of motion for the Air Bag were developed by modeling the Air Bag as a cylinder. The vertical equation of motion was developed by modeling the Air Bag as a parachute. Both the Spec-Net and Det-Net were modeled as flat plates with the area of the plates being the surface area of the respective nets minus the mesh holes in the net. Fragments of the Cherry Bomb are modeled as 7.5 cm^2 (1 in^2) plates. Sufficient information was known in order to model the Bullet as a bullet. Calculations of the equations of motion used to describe the

trajectories of the expendables in the ACME simulation for both Iterations Two and Three are presented in Appendix A, Calculation 14.

As a simplifying assumption, the transition phase from when the expendable is encased in the sphere to when the expendable is fully deployed and considered effective was not modeled. This simplification was based strictly on the excessive complexity of modeling such a transition phase accurately. The dynamics involved during this transition would need to be determined empirically. Therefore, the deployment of the expendable was modeled as occurring instantaneously. Based on the very short time required for the deployment of each expendable, this assumption is considered valid.

5.1.1.2 Aircraft - Missile - Expendable Operation. The basic scenario geometry for the ACME simulation is displayed in Figure 5.2. The diagram describes a rectangular runway with a circle of radius **R** centered about a point on the runway where the C/KC-135 lifts off the ground. The terrorist shooting the missile is located at a point **T** on the circle defined by some angle **A** and the radius **R**. The global origin of the simulation is coincident with the terrorist. The positive **X** and **Y** directions are shown for the right handed global coordinate system.

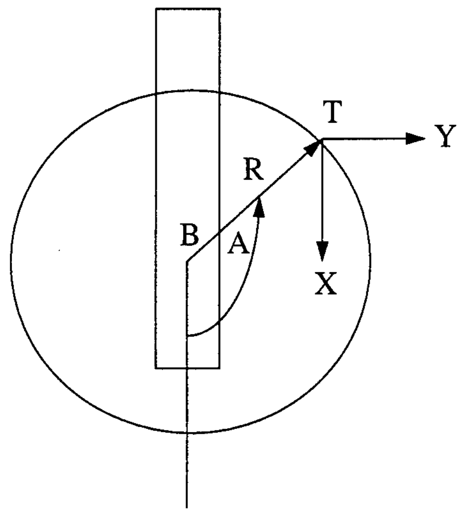


FIGURE 5.2 Basic Scenario Geometry For ACME Simulation

A particular simulation ran as follows. From a standard runway, a C/KC-135 lifts off at point **B** in the diagram above. The terrorist shooting the missile is randomly located at some angle **A** and some range **R**. The angular location was based on a uniform distribution ranging from 0° to 180°. The range location was based on a Rayleigh distribution beginning at 914.4 m (3000 ft) with a mean of 1219 (4000 ft). The Rayleigh distribution was used based on its shape. It is a distribution that looks similar to a Gaussian distribution in that there is a mean value giving the highest probability, in this case of "picking" a particular distance, and there is an infitesimally small probability of "picking" an infitesimally large distance. The reason the Rayleigh distribution was chosen over a Gaussian distribution was that the Rayleigh distribution has a minimum value, in this case a distance, which can be "picked". This was important since shoulder launched SAMs have a minimum distance to target at which they can be launched. For the Stinger missile, that minimum distance is 914.4 m (Huges, 1993). The mean distance of 1219 m is based on the average secured perimeter around an airfield.

At some random time after liftoff, the terrorist, located at point **T**, shoots the missile at the aircraft. This random time was based on a Rayleigh distribution starting at 0 seconds with a mean of 3 seconds. The Rayleigh distribution was again used based on the same characteristics defined in the previous paragraph. Although the launch time after liftoff could possibly be infinite, there is definitely some lower bound, 0 seconds, and some average time after liftoff at which the terrorist would shoot the missile. The mean value was a subjective determination made by the GSE-95D Systems Engineering Team. Once the missile is launched, the simulation continually monitored the slant range between the missile and the aircraft. If the missile gets within 30 m (100 ft) of the aircraft, the aircraft was considered destroyed.

At some random time, the detection system aboard the C/KC-135A aircraft detects the incoming missile. This random time was based on a Rayleigh distribution. The starting point of the distribution was based on the detection system manufacturer's option as to the minimum amount of time after launch it will take the detection system to identify an incoming missile. The mean time is similarly based on the manufacturers opinion of the average amount of time after launch it will take for the detection system to identify an incoming missile. Again, as described in the previous two paragraphs, the Rayleigh distribution was used based on the fact that there is some minimum and some average time it will take a detection system to identify a threat, but the maximum time is theoretically infinite. At this point, one of two things may occur. If only a detector (no tracker) is onboard the aircraft, a launch delay will be calculated based on the average velocity of a shoulder launched missile and the most likely distance from the aircraft it is

believed the missile would be at the time of detection. Once this delay has elapsed, the expendable(s) is (are) launched. If a tracker is onboard the aircraft, it will track the incoming missile once it is detected. Using the tracker's range, bearing, and velocity information, a time of launch was calculated. The azimuth and elevation at which the launcher aims are linearly interpolated from look-up tables. These tables were precalculated for each expendable.

While the azimuth launch angle has a possibility of being any value from 0° to 360°, numerous simulations show that the elevation launch angle is limited to 93° ± 1.3°.(See Appendix C for calculations) In other words, the missile consistently intercepts the 30m (100 ft) radius sphere at an elevation angle of approximately 93°. The 93° elevation angle makes intuitive sense when considering the threat missile LOS navigation logic. Missiles employing LOS navigation logic will always end up in a "tail chase" behind the target aircraft. The tail chase missile will achieve altitude quickly, and then close in on the aircraft from an approximately level flight path.

During the period that the expendable was deployed and considered operational, two conditions were continually checked to determine if the expendable has effectively eliminated the threat of the missile. The first condition was that the slant range between the missile and expendable must be less than the *effective radius* of the expendable. This value varied among expendables. The *effective radius* of the Spec-Net and Det-Net was defined as the radius of a circle inscribed on the face of the net. The *effective radius* of the Air Bag was defined as the radius of a circle inscribed on the vertical cross-section of the cylinder modeling the Air Bag. The *effective radii* of the Bullet and Cherry Bomb were

defined by circular "walls of lead" resulting from multiple Bullets and fragments respectively. The size of the Bullet's "wall of lead" was based on the dispersion rate of the Vulcan 20 mm gun. Calculations defining the size of the Cherry Bomb's "wall of lead" during Iterations Two and Three are presented in Appendix A, Calculations 8 & 12 respectively. Figure 5.1 displays the effective radius of each expendable.

The second condition that must be met in order for the expendable to effectively eliminate the missile threat was that the expendable must be operational while the first condition is met. For example, the Spec-Net and Det-Net were only going to be fully open for a short period of time. After this time has expired, the nets will have sufficiently collapsed to make them ineffective at stopping the missile. The time duration during which the nets were operational was based on information acquired from Foster-Miller, Inc. (Mangolds, 1995). The same limitation existed for the Cherry Bomb and Bullet expendables as well. At some time after deployment, the dispersion of the Cherry Bomb fragments or the Bullets will be so great that it is unlikely that the expendable will be effective in stopping the missile. The time duration during which the Bullet expendable is operational was based on the burst rate of the Vulcan 20 mm gun (Vulcan, 1989:208). Calculations presented in Appendix A, Calculations 8 & 12 present how the time durations during which the Cherry Bomb was effective during Iterations Two and Three. The Air Bag was unique with respect to operational duration. Due to its parachute design, it was considered operational from the time of deployment until it impacts the ground. Figure 5.3 displays the time durations, after deployment, during which each expendable was considered operational.

Iteration Two

Expendable	Effective Radius (m)	Operational Duration (s)
Air Bag	1.10	Indefinite
Bullet	0.37	2.0
Cherry Bomb	6.10	0.1
Det-Net	4.60	3.5
Spec-Net	5.50	3.5

Iteration Three

Expendable	Effective Radius (m)	Operational Duration (s)
Cherry Bomb	1.5	0.002
Det-Net	3.5	3.500
Spec-Net	3.1	3.500

FIGURE 5.3 Effective Radius and Operational Duration

The simulation ends when either the expendable effectively renders the missile inoperable or the missile enters the aircraft's lethal sphere.

5.1.1.3 Aircraft - Missile Expendable Noise. Noise was entered into the simulation at various points in order to create a more realistic simulation. Table 5.1 defines the simulation parameters on which noise was placed, the statistical distribution defining the noise, and the specific statistical parameters defining specific the distribution.

TABLE 5.1 ACME Simulation Noise Parameters

Aircraft Velocity (m/s)	Normal	Mean = 0	Standard Deviation = 2.04
LOS Angle Between Missile & Aircraft as Perceived by Missile (deg)	Normal	Mean = 0	Standard Deviation = .75
Normal Acceleration of Missile (% of True Normal Acceleration)	Normal	Mean = 0	Standard Deviation = 1
Azimuth and Elevation to Missile as Perceived by Aircraft (deg)	Normal	Mean = 0	Standard Deviation = *
Range to Missile as Perceived by Aircraft (m)	Normal	Mean = 0	Standard Deviation = *
Missile Velocity as Perceived by Aircraft (m/s)	Normal	Mean = 0	Standard Deviation = **

* Three Standard Deviations Based on Accuracy Defined in Tables 4.4 - 4.6

** Tracker Dependent

The Gaussian or Normal distribution was used to characterize the noise on each of the parameters defined in Table 5.1 because the deviation of the various parameters from their ideal value had an equal probability of being positive or negative, and could theoretically go to infinity in either direction. The mean value of all Normal distributions was set to zero because, ideally, each parameter should not deviate from its nominal value. In other words, the aircraft's ideal climb velocity should by 82 m/s, but the aircraft has an equal probability of being above or below that value. The standard deviation of the normal distribution defining the noise on the aircraft's velocity is based on half of the allowable deviation from the aircrafts ideal climb velocity of 82 m/s as defined in the KC-135 flight manual. The standard deviations of the normal distributions defining the noise on the LOS angle between the missile and the aircraft as perceived by the missile and the normal acceleration of the missile values that seemed reasonable to the GSE-95D Systems Engineering Team. Actual values which could be used to define these standard deviations were found to be classified. The standard deviations of the normal

distributions characterizing the noise on the last three parameters defined in Table 5.1 are based on information acquired from the manufacturers of the detection and tracking systems on which the composite detection and tracking systems described in Table 4.3 through Table 4.6 are based.

Along with the noise entered into the simulation for the simulation parameters defined in Table 5.1, noise was also placed on the position of the expendable in order to simulate the effects of the aircraft's boundary layer and wing down-wash affecting the trajectory of the expendable. Unlike those parameters defined in Table 5.1, noise was injected separately into the X, Y, and Z position vectors of the expendable. At each instant in time, a noise vector was calculated which altered the path of the expendable from its original launch trajectory. The change in trajectory was modeled as three separate Gaussian noise vectors which were added to the X, Y, and Z position of the expendable at each instant in time. These noise which defined these three separate vectors is defined in Table 5.2. The standard deviation of 0.25 m is an estimate made by the GSE-95D Systems Engineering Team. The sensitivity analysis presented in Chapter VII explores the effects of altering this standard deviation.

TABLE 5.2 Expendable Trajectory Noise Parameters

Expendable X, Y, & Z Trajectory (m)	Normal	Mean = 0 Standard Deviation = 0.25

The deviation of the expendable's flight path at one instant in time is added to the deviation of the expendable's flight path calculated at the previous instant in time. The noise only effects the expendable for the first 0.05 seconds of flight. This is the time it

takes for the expendable to clear the wing of the aircraft. Following the 0.05 second period, the expendable's cumulative trajectory deviation is maintained throughout the remainder of the expendable's flight.

5.1.1.4 PK Calculation. The probability that the expendable kills the missile was based on how close the expendable gets to the missile and at what time this proximity occurs. It was assumed that if the expendable contacts the missile, the missile is destroyed. This assumption was considered valid based on two facts. First, a majority of the shoulder launched missiles have contact fuses (Doherty, 1995). If the missile is slowed quickly enough by an opposing force, in this case the result of an impact, the missile will detonate and destroy itself. Second, based on the known mass of each expendable, the mass of the missile, and the average relative velocity at impact, it has been calculated that each expendable can decelerate the missile so as to detonate the missile. See Appendix A. The PK for each system was calculated by averaging the number of kills for 100 runs of ACME simulating that particular system. Clearly, the more runs of the ACME simulation, the higher the confidence in this PK calculation. The GSE-95D Systems Engineering Team would have liked to run the ACME simulation several thousands of times for each aircraft defense system in order to calculate an accurate PK, but 100 time was deemed sufficient for the level of accuracy attainable by the other seven models presented in this chapter. The PK for the AMM system was not calculated using the ACME simulation. TRW™ defines the ACIDS's PK to be 85% for all possible engagement scenarios. Since the scenario considered in this thesis does not entail as much maneuvering as would a air-to-air engagement, the GSE-95D Systems

Engineering Team assumed the ACIDS's PK to be 99%. Although this may seem to be too high an increase in PK, the GSE-95D Systems Engineering Team felt it would be better to err on the conservative side and give the AMM system the benefit of the doubt. The "doubt" being the GSE-95D Systems Engineering Team's lack of information on how TRW calculated the ACID's PK. This was considered proprietary information.

5.1.2 Passivity. The passivity of a system describes its level of electromagnetic (EM) emissions which can be used by the missile to locate and track the aircraft. There is no standard unit for measuring this emission since it depends on the time duration of EM radiation as well as the level. As a result, the model for passivity is a three level rating system defined in Table 5.3

TABLE 5.3 Passivity Rating System

Rating	Passivity Level
1	Detector and tracker are both active
5	Either detector or tracker is passive
10	Detector and tracker are both passive

5.1.3 False Alarm Rate. The false alarm rate of a system describes how often the detection system identifies an object which is not a threat as an incoming missile. The false alarm rates for current detection systems are classified. Therefore, a relative rating was used to quantify this measurable. A rating of one indicates that the false alarm rate was very poor compared the average false alarm rate for available detection/tracking systems. Conversely, a rating of ten indicates a false alarm rate far lower than the average.

5.2 Environmental Impact Model

The purpose of this model was to rate the impact candidate aircraft defense systems have on the environment. Environmental impact was modeled through comparison in two areas, Harmful Pollutant Effects and Collateral Damage. Regarding pollutant effects, expendables were rated on how their material composition affects the environment. The potential for harm to humans, animals and plant life are all considered in this rating. Regarding collateral damage, the adverse environmental impact resulting from the falling expendable was considered. Rating factors in this category were based on the potential for human injury and the potential for property damage.

5.2.1 Harmful Pollutant Effects. To rate the subcategory of Harmful Pollutant Effects, an expendable was subdivided into the basic materials of which it is composed. These materials were then compared to a list of known harmful agents listed in the CRC Practical Handbook of Environmental Control (Straub,1989:36-60). For each agent listed, the severity of harmful effects on humans, animals and plant life are listed as a function of concentration levels and length of exposure. Based on the findings in this handbook, a score of 1 to 10 was defined for each expendable.

5.2.2 Collateral Damage. The subcategory of Collateral Damage was subdivided into the effects of collateral damage on human injury and the effects of collateral damage on property. Two physical properties of the deployed expendable, temperature and kinetic energy, were calculated in order to quantify the degree of human injury and property damage which would result from a particular expendable.

The temperature of the expendable was defined at the instant the expendable impacts the ground. The temperature of expendables such as the Cherry Bomb (specifically its fragments) and the Bullet, will have impact temperatures exceeding ambient air temperature due to high skin friction drag. The Spec-Net, Det-Net, and Air Bag travel at relatively slower velocities, and will have impact temperature very close to ambient air temperature.

It was difficult to generalize the expendable's velocity upon impacting the ground since the expendables true velocity varies depending on the altitude of the aircraft when the expendable was launched. A simplifying assumption which accounts for the worst case scenario was made by defining the velocity with which the expendable impacts the ground as being its terminal velocity. Consequently, the expendable's terminal velocity was used to calculate its kinetic energy as it impacts the ground. The area over which the expendable's kinetic energy is distributed was not included in the calculation. This simplification was justified because the surface area of the expendable is inversely proportional to the probability of contact. An example best illustrates this logic. Due to its small surface area, a falling piece of metal has high kinetic energy per area but a low probability that the metal will strike a person. In contrast, a falling balloon, with a large surface area has low kinetic energy per area but a high probability of contact. Essentially, the affects of surface area on the collateral damage calculations cancel each other out. This allows for a direct comparison of expendables based on kinetic energy.

5.3 Impact on Aircraft Model

The purpose of this model was to rate the impact of the candidate aircraft defense systems on the C/KC-135 aircraft. The impact on the aircraft was modeled as a set of objective parameters. The basic aircraft defense system requirements of geometry, weight, power, and interface requirements were assessed. The five measurables calculated in this model were the following:

1. Displacement - The required volume of all components divided by the total volume available
2. Weight (N) - Total weight of system and all components
3. Interface Requirements - Number of interfaces required between aircraft defense system components and current aircraft systems
4. Power - Total power required (kW) divided by 80% of the total aircraft power available
5. Center of Gravity (m) - Maximum possible CG travel due to system installation divided by allowable CG travel

The geometry measurements were based on modeling the system components as cubes. Each cube was then compared to the existing cubic space available. Power requirement calculations assumed that C/KC-135 aircraft uses the MIL BUS 1553 (Central Aircraft bus).

5.4 Impact on Mission Model

The purpose of this model was to rate the impact of candidate aircraft defense systems on the ability of the C/KC-135 aircraft and crew to accomplish the mission. The model was designed around the wartime mission of the C/KC-135 aircraft which is the

same for both Active Duty Air Force and Reserve Air Force roles. A primary mission is that of Strip Alert. In this mission, an aircraft is placed at a forward location in a fast response posture. Upon relay of orders to the crew, the aircraft immediately takes off to perform its mission. The strip alert status requires forward positioning of the aircraft such that it may be seen on the field by those from a distance. There is no time to secure a large area around the field prior to takeoff.

The mission impact of a candidate aircraft defense system was determined by comparing the systems in the following four areas.

1. Range Degradation (km) - The difference between the total fuel capacity of a standard C/KC-135 and the modified C/KC-135 multiplied by the ratio of aircraft range per pound of fuel (JP-8) at a flight altitude of 3048 m (10,000 ft) mean sea level.

2. Endurance Degradation (min) - The difference between the total fuel capacity of a standard C/KC-135 and the modified C/KC-135 divided by the ratio of the amount of fuel consumed (JP-8) per unit time at a flight altitude of 3048 m (10,000 ft) mean sea level.

3. System Isolation Capability (Yes or No) - Can the modified system be completely isolated from all other aircraft systems without impacting performance of the other systems?

4. On Time Takeoff Prevention (Yes or No) - Can the modified system, if inoperable, prevent an on-time takeoff by forcing the removal of mission critical aircraft components?

5.5 Installation Requirements Model

The purpose of this model was to rate the impact of modifying a C/KC-135 with a particular aircraft defense system. This characteristic of the candidate aircraft defense systems was quantified by the man hours required to install the aircraft defense system and the number of personnel required to accomplish this task. Both of these measurables were dependent on the size and location of the system. For rating purposes, the amount of structural changes required and the amount of integration with current systems were both considered when determining these two measurables.

5.6 Life Cycle Cost Model

The purpose of this model was to assign candidate aircraft defense systems a ranking based on their Life Cycle Cost (LCC). For the remainder of the cost model description, the term cost will refer to monetary cost in 1995 U.S. dollars. As stated in the *Problem Definition* phase, the projected life time of the aircraft defense system is 20 years. The LCC model was an estimation of the total cost of a system from its inception to a time when it is no longer in use. According to Airplane Design VII: Airplane Cost Estimation - Design, Development, Manufacturing and Operations on which this LCC model was based, the primary components of the LCC model are research, development, test, and evaluation costs (C_{rdte}), acquisition costs (C_{acq}), operation costs (C_{ops}), and disposal costs (C_{disp}) (Roskam, 1985). Profit costs were not included in this model based on the assumption that these costs are equal for all candidate aircraft defense systems. The LCC of a system results from the following summation, the components of which are described in sections 5.6.1 through 5.6.4.

$$LCC = C_{rdte} + C_{acq} + C_{ops} + C_{disp}$$

5.6.1 RDT&E Cost. The following are components of RDT&E cost.

1. System engineering and design costs
2. System component integration cost
3. Aircraft/system integration cost
4. Flight test cost
5. Test and simulation facilities cost

Based on the excessive inaccuracies involved with estimating each of these component costs of RDT&E for a general feasibility study such as this thesis, the best assessment of RDT&E cost was accomplished by simply estimating the cost as a single value. In other words, in lieu of estimating subdivisions of the total cost and subsequently summing those subdivisions, the entire RDT&E cost for a system was estimated as a single dollar amount. These estimations were based on RDT&E cost of existing aircraft defense systems such as the flare system used aboard the B-1B aircraft.

5.6.2 Acquisition Cost. Components of the acquisition cost were based primarily on the manufacturing and installation costs for the detection, tracking, launch, and expendable subsystems. As a result of the format in which detection and tracking system cost data are available, the acquisition cost of these two subsystems is defined as one value. The number of each subsystem used for a particular aircraft defense system was the primary driving force behind the entire system's acquisition cost. The following calculation was used to quantify the aircraft defense system acquisition cost.

$C_{acq} = DTS_{cost} + LS_{cost} + (Exp_{cost})(\text{Number of Exp per aircraft})$

Where:

DTS = Detection and Tracking System

LS = Launch System

Exp = Expendable

5.6.3 Operations Cost Development. The cost of operating a system during its life cycle was based on the maintenance rating of the system, the number of spares required for each subsystem, and the system's energy requirements. The maintenance rating, which is described in section 5.7, was based on the reliability of the system. As a result of the requirement that the aircraft defense systems operates for 20 years, and assuming an operations cost of $50,000 per year, the base operation cost was calculated to be $1,000,000. By the same logic presented with regard to detection and tracking system acquisition cost, the detection and tracking systems operations cost was defined as one value. The following calculation was used to quantify the aircraft defense system operation cost.

$Cops_2 = 1000000 - (\text{Maintenance Rank})(10,000)$

$$Cops = Cops_2 + \text{Energy cost} + (\text{Number of } DTS_{spares})(DTS_{cost}) + (\text{Number of } LS_{spares})(LS_{cost}) + (\text{Number of } Exp_{spares})(Exp_{cost})$$

5.6.4 Disposal Cost Development. The disposal cost is the cost to retire the system once it has reached the end of its expected lifetime. A good rule of thumb is that disposal cost is approximately 1% of the system's total life cycle cost.

$C_{disp} = (.01)(C_{rdte} + C_{acq} + C_{ops})$

5.7 Maintenance Requirements Model

The purpose of this model was to determine the maintainability of each candidate aircraft defense system. This determination was based on the system's reliability, the man-hours required to maintain the system, and the requirements for special facilities, specialized equipment, testing, and handling. Each system received a maintenance rating (MR) of 1 to 100 from this model.

The most crucial aspect of the maintenance model was the system reliability (Burgan, 1995). The reliability of the entire system is a sum of the subsystems' reliabilities. This assumes that the failure rates of all subsystems are independant and have an exponential distribution. Data entered into the Maintenance model include, the number of failures of each subsystem per 1000 operating hours, the average duration of a sortie, and estimates of the maintenance man-hours per week necessary to maintain the entire system.

The Maintenance model started with an initial maintenance rating (IMR) based on overall system reliability. This IMR was then altered based on the other important maintenance factors. These factors were rated according to their relative importance to system reliability. The number of maintenance man-hours per week was deemed to be the second most important aspect, relative to system reliability, of the maintenance model. Testing was considered the third most important followed by facilities, maintenance equipment, and special handling requirements. The latter three factors, facilities, maintenance equipment, and special handling requirements were all deemed to be equally important, and given the same weighting. The rating of the maintenance

factors was accomplished with the assistance of Maj. Darryl Burgan, a Logistics instructor at the Air Force Institute of Technology with many years of experience as an aircraft maintenance officer (Burgan, 1995).

The maintenance rating for each kinetic kill system was calculated using the following equations (Burgan, 1995).

<u>Maintenance Rating:</u>

$$MR = (IMR - H - F - E - SH - T)(10)$$

<u>Initial Maintenance Rating (IMR):</u>

$$R = e^{-ts}$$

$$s = sf/1000$$

$$sf = x + y + z$$

Where:

t - average sortie duration (ASD), typically 4.3 hrs

f - system failure rate

x - Number of Detection & Tracking System Failures per 1000 hrs

y - Number of Launch System failures per 1000 hrs

z - Number Expendable failures per 1000 hrs

Based on the reliability, R, calculated, the initial maintenance rating was determined from Table 5.4.

TABLE 5.4 Initial Maintenance Rating

R	1.000 - 9.600	0.959 - 0.920	0.919 - 0.880	0.879 - 0.840	0.839 - 0.800	0.790 - 0.000
IMR	10	9	6	4	2	0

Man-hours per Week (H):

Based on the number of man-hours per week required to maintain each system, Table 5.5 was used to calculate the values for "H" in the maintenance rating calculation.

TABLE 5.5 Man-Hour Rating

Man Hrs	0.0 - 5.0	5.1 - 10.0	10.1 - 15.0	15.1 - 20.0
H	0	1	2	3

Facilities (F):

Can existing base facilities be used to maintain the system?

yes - F= 0

no - F= 1

Equipment:

Can existing Maintenance equipment be used to maintain the system?

yes - E= 0

no - E= 1

Special Handling:

Are there special handling requirements for the system?

yes - SH = 1

no - SH = 0

Testing:

T = T1 + T2

Can diagnostic testing be accomplished by external inspection?

yes - T1 = 0

no - T1 = 1

Can subsystems be individually tested?

yes - T2 = 0

no - T2 = 1

5.8 Operator Tasking Model

The purpose of this model was to rate the impact candidate aircraft defense systems have on the flight crew. The model was developed to account for ergonomic and user interface requirements, and was structured as a tree rating scale as displayed in Figure 5.4. The questions asked in the tree rating scale and the resulting weights are based on information acquired from KC-135 flight crews. "Is the System Status Known?" is the first question that is answered in order to calculate the operator tasking rating. Depending on the answer, the corresponding branch leads to the next question which, in turn, depending on the answer, leads to another question until, finally, the appropriate operator tasking rating, contained within the circles, is determined.

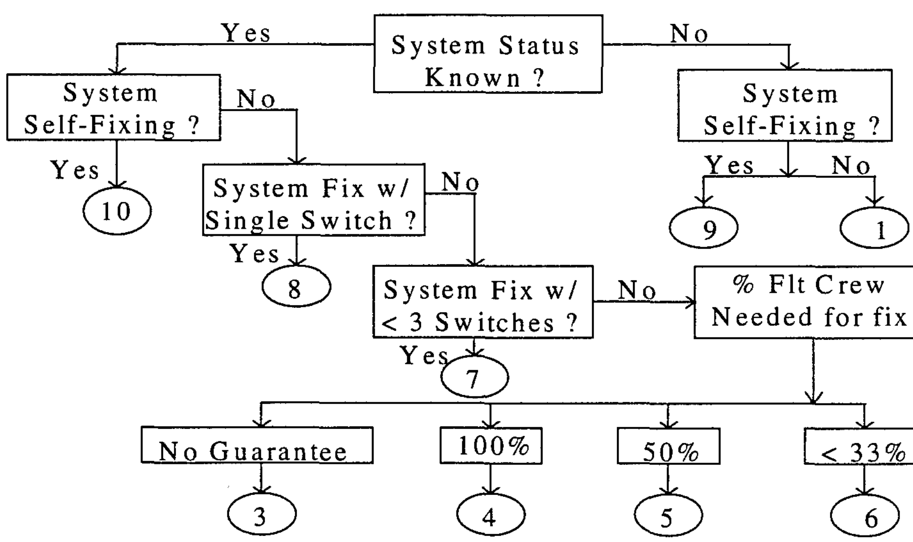


FIGURE 5.4 Operator Tasking

5.9 Iteration Three, Model Improvements

Excluding the Effectiveness model, all of the models described in section 5.8 remained unchanged in Iteration Three. A single modification was made to the ACME simulation. The threat SAM velocity profile is more accurately defined, as described in section 2.6, in order to characterize a Stinger missile. This velocity profile was based on information provided by Wright Laboratory (Voegle, 1995).

VI. System Evaluation

The evaluation of candidate aircraft defense systems in Iteration One consisted of eliminating those expendable alternative considered infeasible. At that phase of the study, not enough information was known about the remaining subsystems to eliminate any of the alternatives. Further research conducted in Iterations Two and Three resulted in a clearer pictures of all subsystem alternatives. All feasible subsystem alternative were evaluated during these two iterations. This chapter presents the evaluation of the candidate aircraft defense systems considered in Iterations Two and Three.

6.1 Iteration Two

Utility charts presented in Appendix D are developed for each of the system characteristics defined in *Value System Design*. Two sources of information, current literature and personal interviews, were primarily used to develop these utility charts. Information from current literature defined the nominal range of performance for the various system characteristics defined in *Value System Design*. For example, current literature indicates that a defense system with a PK less than approximately 80% is not very useful (Schaffer, 1993). Consequently, the median utility score of 50 was assigned to a PK value slightly less than 80%. The utility score of 100 was assigned to a PK of 100%, and the utility score of 1 was assigned to a PK of 10%. A curve was then fit between these three points in order to define how the remaining utility scores corresponded to the remaining PK values. Table 6.1 presents the utility chart for this example in tabular form.

TABLE 6.1 Probability of Kill Utility Chart

PK	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Utility	100	80	60	40	30	20	15	10	5	1

If current literature was unable to define maximum, minimum, and nominal performance of the measurables defined in the *Value System Design*, this information was obtained from experts who have experience with that particular measurable. For example, a good deal of the information required to define nominal performance of those measurables defined in the maintenance model such as the initial reliability of a system and the man-hours per week required to maintain a system was learned through interviews with Major Darryl Burgan, an instructor in the school of Logistics at the Air force Institute of Technology, who has several years of experience as an aircraft maintenance officer.

Along with defining utility charts, weighting factors for each of the system characteristics defined in the *Value System Design* were also defined. The weighting factors are based on feedback from the Electronic Warfare Division of Wright Laboratory regarding the importance of specific performance levels attained by the aircraft defense system and the relative importance of each of the system characteristics. Specifically, the GSE-95D Systems Engineering Team defined what we felt were appropriate weighting factors for each of the characteristics defined in the *Value System Design*. These weighting factors were then given to the Electronic Warfare Division for review. Changes were made to certain weighting factors such as PK and cost, and the resulting weights were then used for Iteration Two. These weighting factors are presented in the evaluation tables displayed in Appendix E. A sample of these tables is presented in Figure 6.2.

The relative accuracies of each measurable are all normalized to a value of 1.0. during Iteration Two. This normalization is justified based on the comparative nature of this study. In this thesis, relative comparisons are being made solely between candidate defense systems. Consequently, only relative confidence values are required to make accurate comparisons between candidate aircraft defense systems. Because the relative confidence among a majority of the measureables calculated during *System Modeling* are the same, the bulk of these measurables were all given a normalized confidence rating of 1.0. The exceptions to this generalization were the PK values for the candidate aircraft defense which employed the Air Bag and Spec-Net using tracker Composite #1. The GSE-95D Systems Engineering Team was not as confident about the effective area, the surface area which can effectively be used to stop the SAM, calculated for the Air Bag and Spec-Net. Similarly, the Team was not as confident about the range accuracy of tracker Composite #1 relative to the other trackers. Consequently the confidence values for candidate aircraft defense systems employing either the Air Bag or the Spec-Net using tracker Composite #1 were given confidence ratings of 0.8. If the candidate aircraft defense system employed the Air Bag or the Spec-Net but some tracker other than Composite #1, the system was given a confidence rating of 0.9.

The Table 6.2 summarizes the evaluation process for a particular candidate aircraft defense system considered in Iteration Two. There is one table for each of the 40 candidate aircraft defense systems defined by the subsystem alternatives presented in Table 4.7 along with an evaluation table for the AMM system presented in Appendix E. Entered into each table are the weight, utility score, and confidence level for each

measurable. Calculated in each table are the *Raw Utility Score* and *Discounted Utility Score*.

TABLE 6.2 Sample System Evaluation Table

SYSTEM - Tracker 1, Air Bag, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	16.00	4.88	0.80	3.90
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	70.00	0.70	1.00	0.70
Endurance	0.02000	30.00	0.60	1.00	0.60
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	42.50	0.51	1.00	0.51
Property Damage	0.00300	42.50	0.13	1.00	0.13
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			60.56	0.99	59.59

6.2 Iteration Three

All utility charts and weighting factors defined during Iteration Two remained the same for Iteration Three. Based on refinements made to the remaining candidate subsystems, the confidence ratings for the system characteristics defined in *Value System Design* were appropriately modified. Using the models developed during Iteration Three *Systems Modeling*, performance levels were calculated for each of the system characteristics defined in *Systems Synthesis*. Using the existing utility charts, the *Raw Utility Scores* corresponding to the appropriate performance level were then calculated. These new *Raw Utility Scores* calculated for all six Iteration Three aircraft defense system alternatives as well as the corresponding *Discounted Utility Scores* are presented in evaluation tables presented in Appendix E.

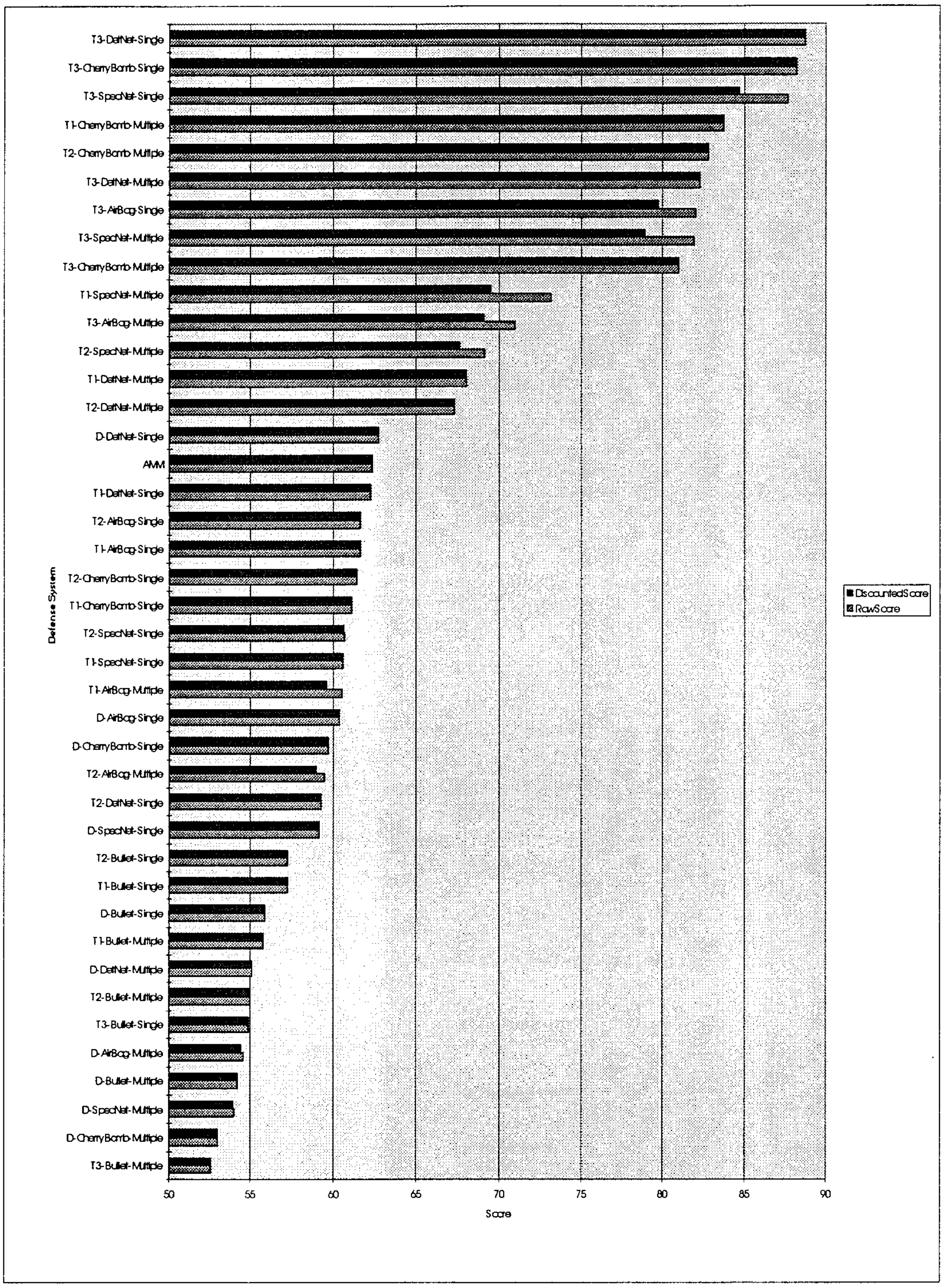
VII. Decision Making

During Iteration One, decisions were made as to which expendable designs were considered the best. During this iteration, the definition of "best" was based on a subjective determination of how well each expendable would perform relative to the system characteristics defined in *Value System Design*. Due to lack of information on the other subsystem alternatives, decisions were not made in Iteration One as to which complete aircraft defense systems (detector, tracker, launcher, and expendable) were the best. Decision regarding which complete candidate aircraft defense systems were considered the best were made during Iterations Two and Three. During these last two iterations, the definition of "best" was still based on a determination of how well each expendable performed relative to the active aircraft defense system characteristics defined in *Value System Design*. However, this determination was not completely subjective during Iterations Two and Three. At this point, the performance of candidate aircraft defense systems was quantified using the models defined in Chapter V, *Systems Modeling*. This chapter presents the decisions made during Iterations Two and Three regarding which aircraft defense systems were the best.

7.1 Iteration Two

The top two scoring systems in Iteration Two (based on *Discounted Utility Score*), the Cherry Bomb and Det-Net, both employing Tracker Composite #3 and a single expendable, were chosen for further study in Iteration Three. The third top scoring system, Spec-Net, employing Tracker Composite #3 and a single expendable launch, was

also chosen for further study due to its high *Raw Utility Score*. All Iteration Two system scores are graphically presented in Figure 7.1. Numerical values corresponding to the bar chart displayed in Figure 7.1 are located in Appendix F.



TX = Tracker Composite #X
Single = One Expendable Capable of Launch

D = Detector Only, No Tracker
Multiple = Seven Expendables Capable of Launch

FIGURE 7.1 Iteration Two Evaluation Results

Iteration Two presents some interesting results. Prior to this iteration, the GSE-95D Systems Engineering Team believed that an aircraft defense system employing a multiple expendable launch capability would be superior to a similar defense system supporting only a single expendable launch capability. Results of Iteration Two indicated the opposite to be true. Clearly, if one evaluates an aircraft defense system only on effectiveness, a system employing a multiple launch capability would be the best. In contrast, if one evaluates an aircraft defense system on all of its important aspects such as cost, maintainability, etc., as well as effectiveness, as is done in this thesis, the impact on the overall utility of a particular aircraft defense system is realized. Utility here is defined as the overall worth of the system. In the case of multiple versus single expendable launch capability, the monetary cost of incorporating multiple expendables into an aircraft defense system significantly decreased the overall utility of the system.

Based on similar reasoning, the AMM system, when evaluated according to the measurables defined in *Value System Design*, was not considered better than those aircraft defense systems employing "dumb" expendables. This was the result of the large monetary cost involved with systems employing a "smart" expendable.

Because the weighting factor associated with cost defined in *System Evaluation* is relatively high, the cost of an aircraft defense system significantly affects its overall utility. Similarly, the weighting factor associated with the effectiveness, or more specifically the PK of a system, is also relatively high. Results of Iteration Two indicate that those expendable designs with the largest effective area, the area of the expendable which can be used to impact the missile, have the highest PK. Consequently, those

aircraft defense systems with a large effective areas also have a high overall utility. This conclusion is supported by the fact that the Cherry Bomb, Det-Net, and Spec-Net all have large effective areas, 117 m^2, 66 m^2, and 95 m^2, relative to the other two candidate expendables, the Air Bag and Bullet which have effective areas of 4 m^2 and 0.4 m^2 respectively.

Along with effective area significantly driving the PK of a system, the accuracy of the tracking system employed by the aircraft defense system also played a very large role in the PK of the aircraft defense system. Results of Iteration Two indicate that the better the tracker, the higher the PK of the system. More specifically, it was the ability of the tracker to measure the range of the threat missile that drove the PK of the system. This conclusion is supported by the fact that differences among the bearing accuracies of tracker Composites #1, #2, and #3 are at most 5.95°. In contrast, there are significant improvements in range accuracy among tracker Composites #1, #2, and #3. Specifically, as presented in Table 4.4 through Table 4.6, the bearing accuracy of tracker Composite #3 is three orders of magnitude more accurate than either of the other two tracker composites. As a result, those aircraft defense systems which employed tracker Composite #3 were more effective than those that employed either of the other two trackers. The results of Iteration Two presented in Figure 7.1 support this finding.

In summary, due to the relatively high weighting factors defined in *System Evaluation*, the cost and effectiveness of the each aircraft defense system significantly drive the overall utility of the systems. More specifically, it is the cost of the system, the effective area of the expendable, and the range accuracy of the tracker which define how

much better one aircraft defense system is versus another. Figures 7.2 presents the average PK calculated for each candidate aircraft defense system during Iteration Two. This characteristic of the candidate systems, driven by expendable effective area and tracker range accuracy, significantly affected the determination of the optimal system during Iteration Two. The cost of each of the Iteration two candidate aircraft defense systems is presented in Figure 7.3 and Figure 7.4. Figure 7.4 presents the same results and Figure 7.3 without plotting the cost of the AMM system. Figure 7.2 through Figure 7.4 provide a quick reference for those system characteristics which significantly affected the overall results of Iteration Two.

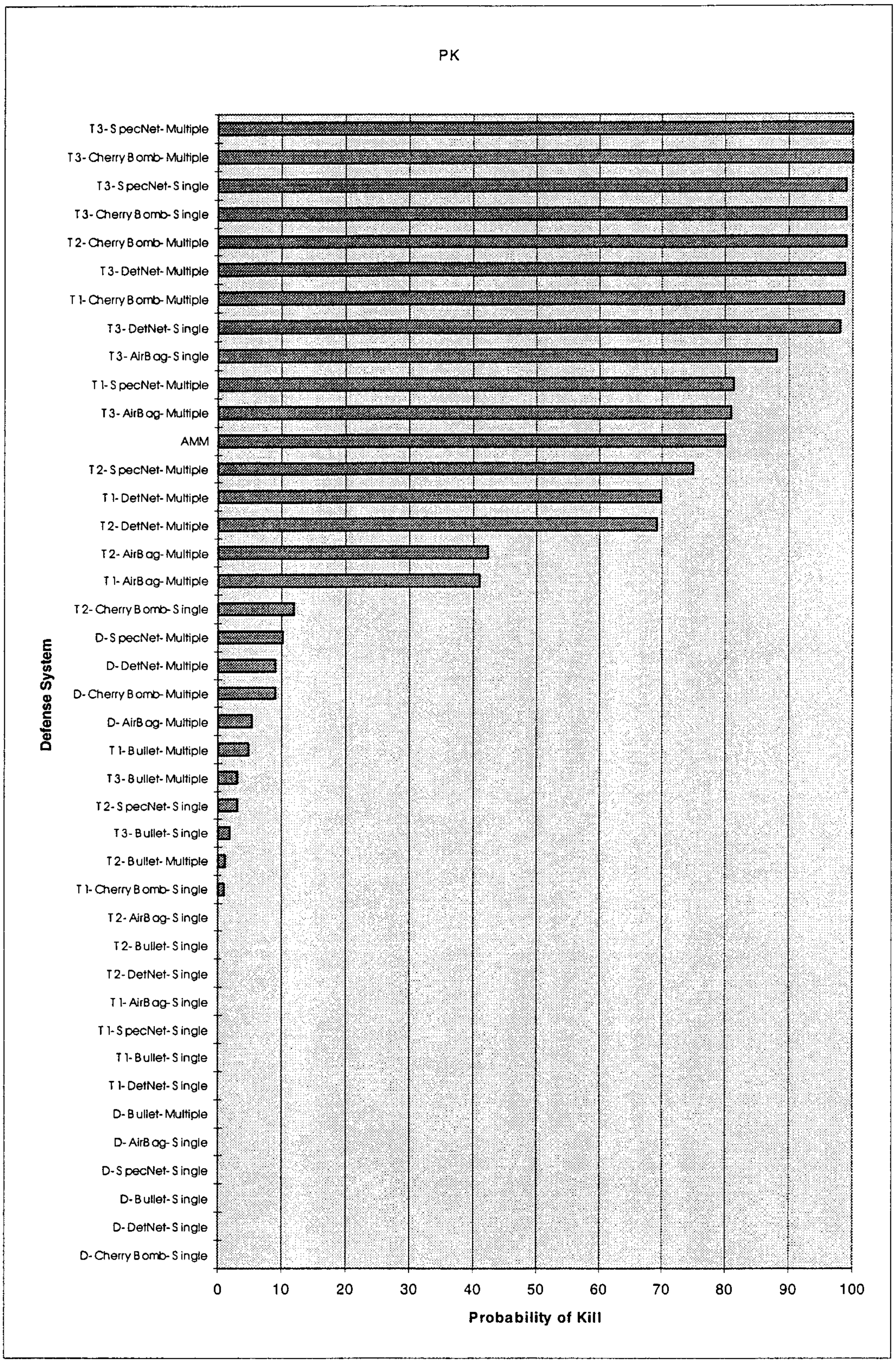


FIGURE 7.2 Iteration Two Probability of Kill

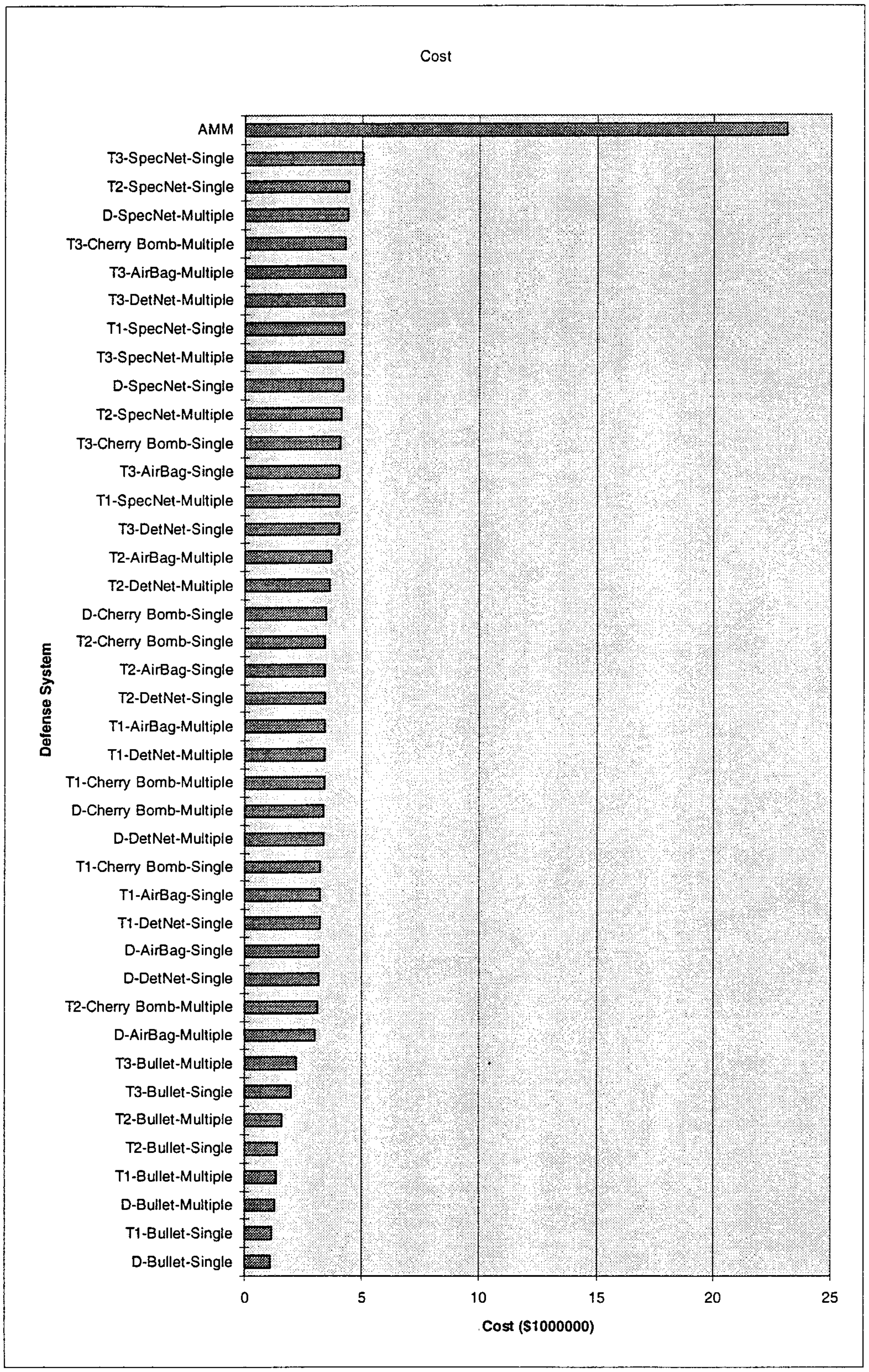


FIGURE 7.3 Iteration Two Monetary Cost

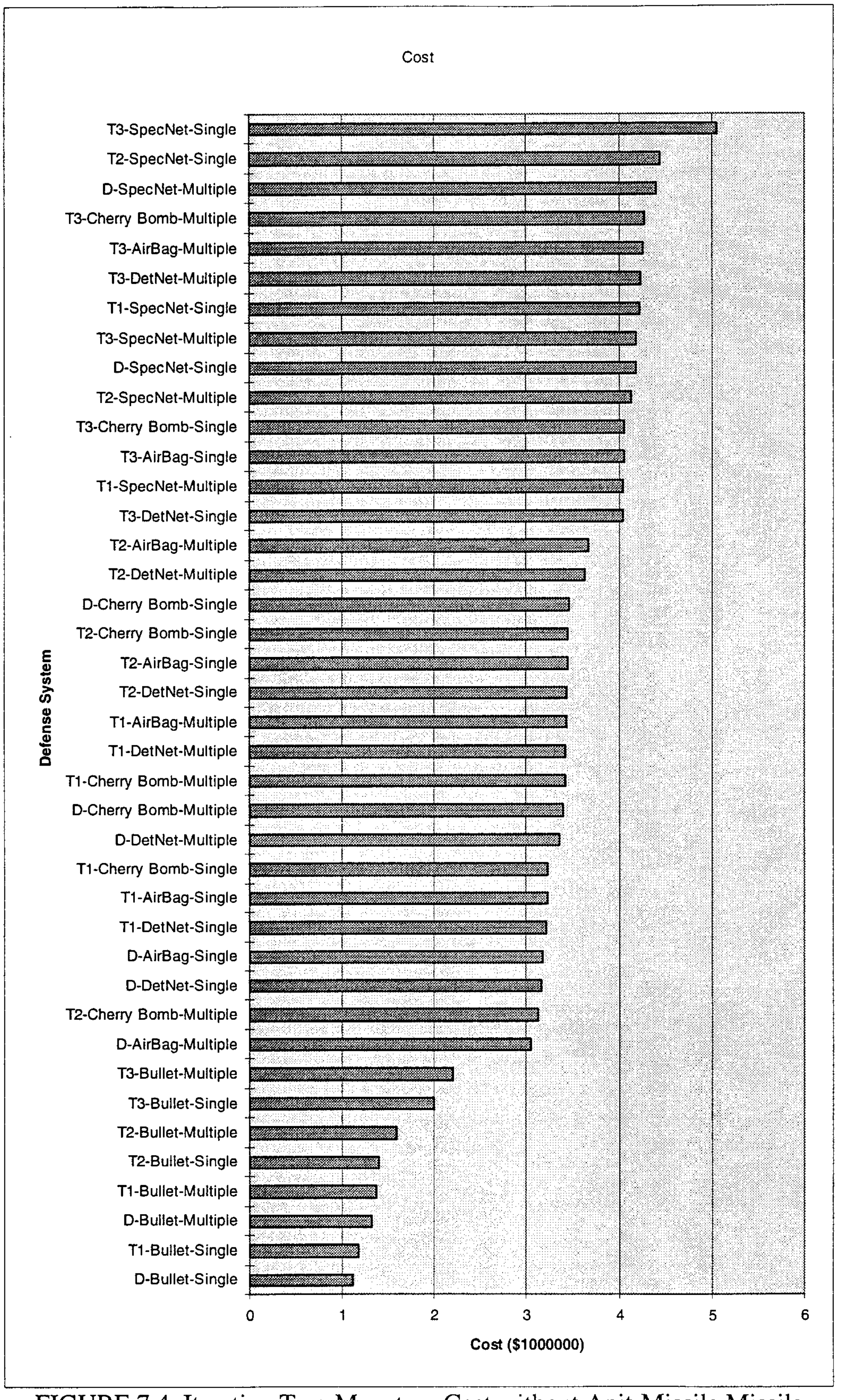


FIGURE 7.4 Iteration Two Monetary Cost without Anit-Missile Missile

7.2 Iteration Three

The Spec-Net and Det-Net, both using tracker Composite #2a and launching a single expendable, are considered to be the best aircraft defense system designs. With a difference in *Raw Utility Score* of 0.34 and *Discounted Utility Score* of 0.24, these two systems effectively tied for the top position. Figure 7.5 displays the results of the Iteration Three evaluation.

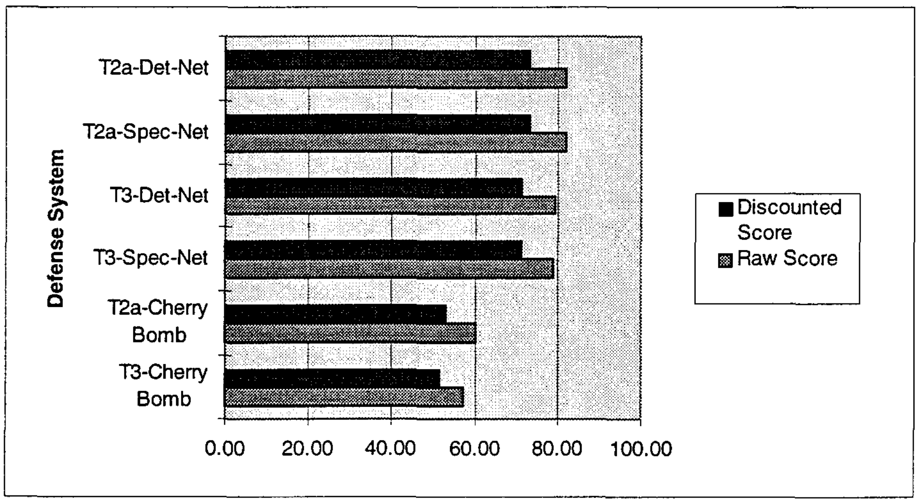


FIGURE 7.5 Iteration Three Evaluation Results

This tie displays a true strength of the Systems Engineering Process in being able to articulate and quantify the trade-offs between these systems, in terms of the *Value System Design*, weighting factors, and confidence ratings. Although both systems are optimal, they are optimal for different reasons. For example, the Det-Net costs more than the Spec-Net, but the Det-net also has a higher PK than the Spec-Net. Similarly, the Det-Net is more harmful to the environment than the Spec-net, but the Det-net is less harmful to

the aircraft (less CG travel) than the Spec-Net. Both systems have their strong and weak points. The Systems Engineering process does an excellent job of defining what those strengths and weaknesses are. More importantly, though, Systems Engineering allows one to accurately quantify those strengths and weaknesses in such a way that multiple solutions to a particular problem such as designing an aircraft defense system can equitably be compared.

The results of the third iteration support conclusion made based on Iteration Two results. The new tracker, Composite #2a, possess the important attributes of being both inexpensive as well as accurate in terms of range. As a result, the aircraft defense systems employing tracker Composite #2a have a much higher utility score than those employing tracker Composite #3, which is just as accurate as Composite #2a but more expensive. Iteration Three results also support the conclusion that the larger the effective area of the expendable, the higher the aircraft defense system's PK. The Iteration Three PK utility score for the Det-Net employing tracker Composite #2a was 82. In contrast, the PK for the Spec-Net employing the same tracker was 70. Figures 7.6 and 7.7 present the Iteration Three Effectiveness and Monetary Cost results respectively.

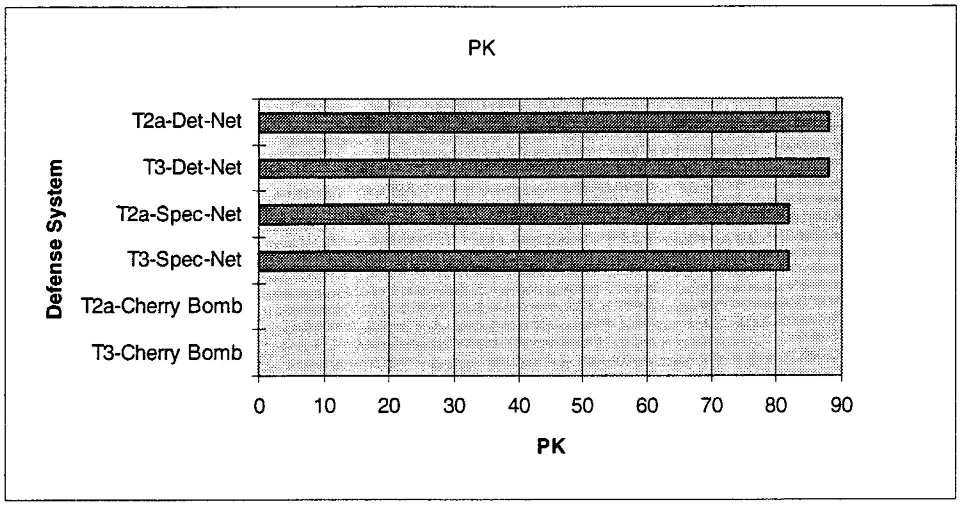


FIGURE 7.6 Iteration Three Probability of Kill

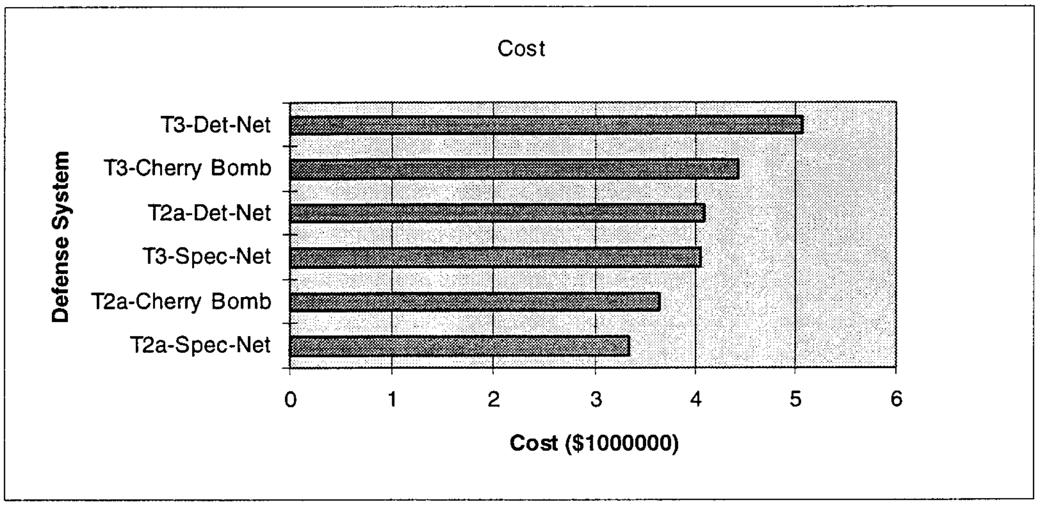


FIGURE 7.7 Iteration Three Monetary Costs

7.3 Expendable Trajectory Sensitivity Analysis

Following the definition of the top two aircraft defense systems in Iteration Three, a sensitivity analysis was performed to determine the extent to which the expendable's launch trajectory is affected by the noise associated with the aircraft's boundary layer and

down-wash. This analysis was performed by altering the standard deviation of the normal distributions defining the noise introduced into the expendable flight path and calculating the resulting aircraft defense system's PK.

7.3.1 Methodology. The sensitivity analysis was performed on the top two systems defined by Iteration Three.

<u>System 1</u>	<u>System 2</u>
Spec-Net	Det-Net
Detector Composite #1	Detector Composite #1
Tracker Composite #2a	Tracker Composite #2a
Single Launch	Single Launch

The ACME simulation was run 100 times with the following six standard deviations and a corresponding PK was calculated.

1. 0 m
2. 0.12 m
3. 0.24 m
4. 0.46 m
5. 0.76 m
6. 1.2 m

The standard deviation of the noise in all three X, Y, and Z direction was the same for a particular 100 run set of the ACME simulation.

7.3.2 Results. The sensitivity analysis indicates that boundary layer and down-wash drastically effect the systems' PK. The results of this analysis, presented in Figure 7.8, display the effects of increasing the standard deviation of the noise on the PK of the two system. As one would expect, the higher the standard deviation, the lower the PK. In physical terms, this means that the larger the boundary layer around the aircraft and/or

the greater the down-wash from the wing, the lower the PK. Instead of presenting Figure 7.8 as a three dimensional graph, a second graph presented in Figure 7.9 displays the corresponding deviation in flight path resulting from the noise in the expendables flight path trajectory. The deviation presented in Figure 7.8 is the deviation of the expendable from its original launched flight path once the expendable has cleared the wing of the aircraft. The noise standard deviation which were used, (0, .12, .24, 0.46, 0.76, and 1.2 meters) resulted in final average noise magnitudes of (1.2, 2.7, 5.1, 8.7, and 14.2 meters, respectively).

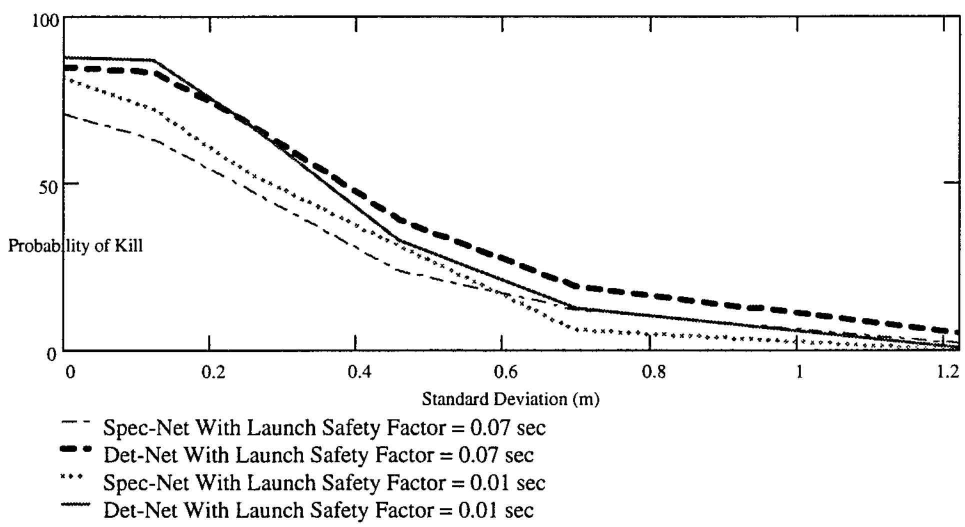


Figure 7.8 PK Versus Expendable Trajectory Noise Standard Deviation

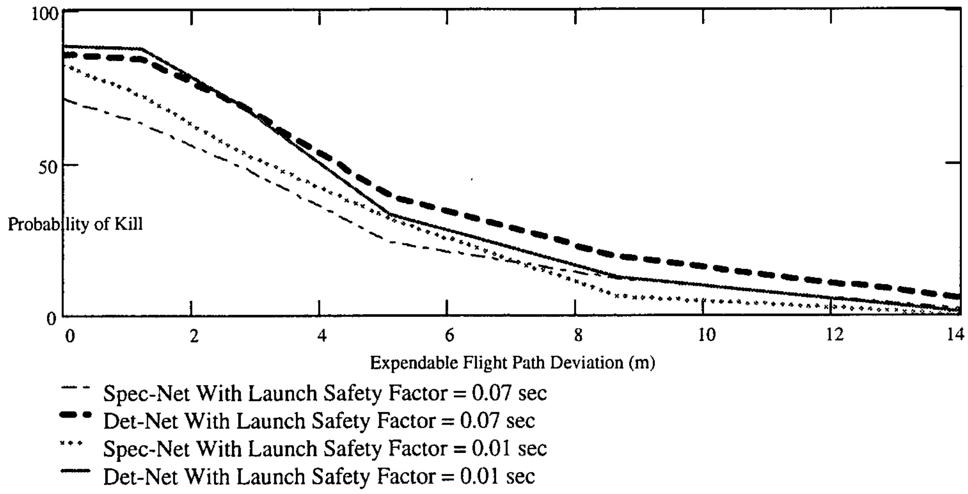


Figure 7.9 PK Versus Expendable Flight Path Deviation

The aircraft defense systems evaluated in this sensitivity analysis originally used a Launch Safety Factor of 0.01 seconds to account for range and velocity tracking errors. In other words, the launch system would launch the expendable 0.01 seconds earlier than it normally would have assuming the tracker's measurement of the missile's position and velocity were perfect. This earlier launch would allow the expendable to intercept the missile at a distance furthur than 30 m (100 ft) from the aircraft. Remember, without this safety factor, the expendable should ideally intercept the missile at a range of exactly 30 m (100 ft). Since the true range from the aircraft to the missile is not known, launching the expendable earlier would provide a safety factor against intercepting the missile after it enters the 30 m (100 ft) radius sphere around the aircraft.

Once the initial results of the sensitivity analysis were reviewed, the safety factor was increased to 0.07 seconds. This decreased the overall sensitivity of each system's PK to the expendable's flight path deviation resulting from the aircraft's boundary layer and

wing down-wash. Figure 7.8 and Figure 7.9 indicate that for both systems, there is a cross-over point in the graphs defined by a safety factor of 0.01 and 0.07. This means that the degree of interference due to the aircraft's boundary layer and wing down-wash defines how long the safety factor should be. This confirmed the hypothesis that the more knowledge the user has about the air flow around the aircraft, the greater the possibility for a higher aircraft defense system PK.

7.4 Cost vs Effectiveness Weighting Factor Sensitivity Analysis

The importance of how the *System Evaluation* weighting factors, as described in section 1.3.5, are chosen can not be overstated. These weights are the driving force behind how one system will rate relative to another. In order to determine how these weighting factors affected the determination of the optimal aircraft defense system, the GSE-95D Systems Engineering Team performed a sensitivity analysis on the Effectiveness and Cost weighting factors.

7.4.1 Methodology. The sensitivity analysis was performed on the top four systems defined by Iteration Three.

System 1	System 2
Spec-Net	Det-Net
Detector Composite #1	Detector Composite #1
Tracker Composite #2a	Tracker Composite #2a
Single Launch	Single Launch

System 3	System 4
Spec-Net	Det-Net
Detector Composite #1	Detector Composite #1
Tracker Composite #3	Tracker Composite #3
Single Launch	Single Launch

The results presented in section 7.2 for Iteration Three are based on a Cost weighting factor of 0.26 and a Effectiveness weighting factor of 0.35. The sum overall sum of the Effectiveness and Cost weighting factors was kept constant, 0.61. Initially, the Effectiveness weighting factor was set to 61% and the Cost weighting factor was set to 0%. This indicated that Effectiveness meant everthing to the user and cost meant nothing. The raw utility score using these weighting factors was then calculated. Next, the Effectiveness weighting factor was decremented by 1% and the Cost weighting factor was incremented by 1%. The raw utility score for all four systems was again calculated. The procedure was then repeated until the PK weighting factor was 0% and the cost weighting factor was 61%.

Note that both the Cost and the Effectiveness characteristics are subdivided into other categories. For example, Effectiveness is subdivided into PK, Passivity, and False Alarm rate. The results of Iteration Three are based on these three categories having weighting factors of 0.31, 0.01, and 0.04 respectively. In other words, 88.6% of the total effectiveness weight (0.31/0.35) is based on PK, 2.9% is based on Passivity, and 8.5% is based on False Alarm Rate. All four Cost category subdivisions evenly effect the overall cost weighting. Consequently, all contribute 25% of the total Cost. When altering the Effectiveness and Cost weighting factors between 0% and 61%, this relative weighting

was maintained. In other words, if the Effetiveness weighting was 10%, the PK weight would be 8.86, the Passivity weighting would be 0.29, and the False alarm rate weighting would be 0.85.

7.4.2 Results. The results of this sensitivity analysis are presented in Figure 7.10.

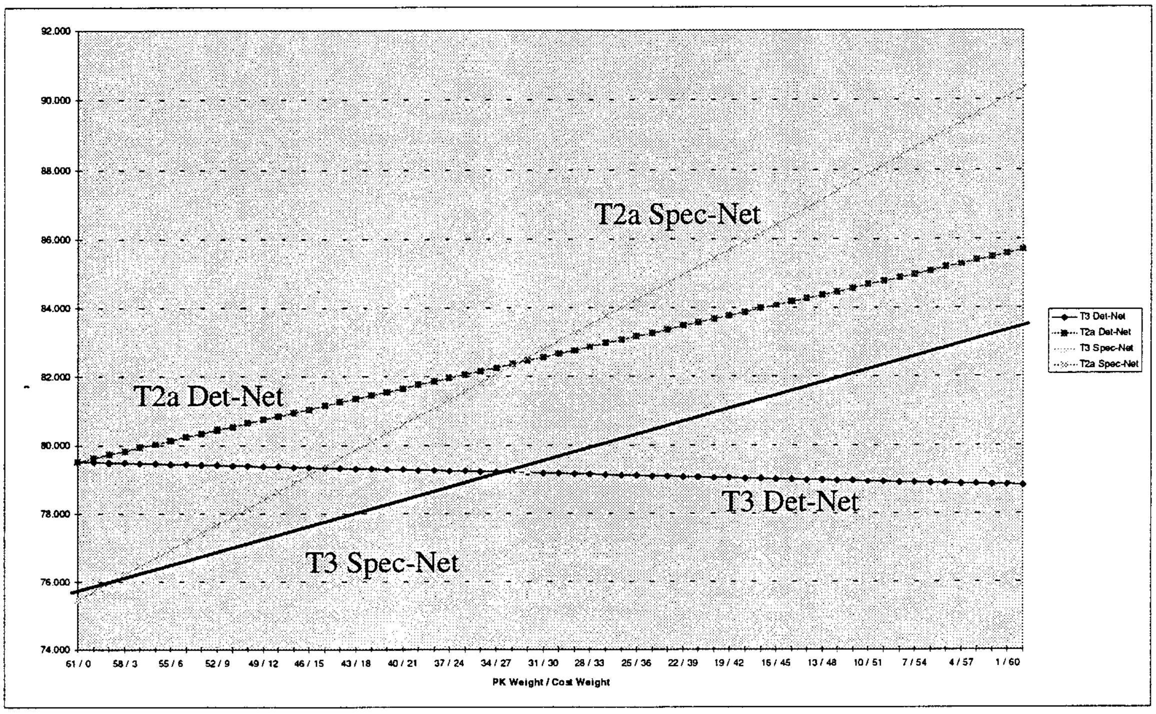


FIGURE 7.10 Sensitivity Analysis of Cost and Effectiveness Weighting Factors

The slope of the plots in Figure 7.10 indicate the degree of sensitivity to Effectiveness and Cost weighting factors. The greater the slope, the greater the sensitivity. Excluding the aircraft defense system employing tracker Composite #3 and the Det-Net, the utility score of all other sytems appear to significantly be affected by the weighting values chosen for Effectiveness and Cost. The results of Iteration Three had, for the most part, already defined the cross-over point of the aircraft defense systems employing the same tracker composite. Although a definite set of weights have to be chosen to determine

which aircraft defense system is optimal, Figure 7.10 clearly shows how changing these weighting factors could affect ones determination of the optimal system.

VIII. Implementation

The results of this thesis, regarding the feasibility and basic design of an aircraft defense system employing a kinetic kill mechanism, present the opportunity for several possible courses of action. This chapter discusses courses of action recommended by the GSE-95D Systems Engineering Team.

8.1 Further Research

The design of the aircraft defense systems presented in this thesis do not possess sufficient detail to warrant their immediate integration into Air Force weapon systems. Further research into the detailed design and testing of these systems is required before an operational system can be fielded. This thesis clearly indicates that a low cost, effective active aircraft defense system employing a kinetic kill mechanism is feasible. Since this thesis did not attempt to provide a complete blue print of the defense system, the GSE-95D Systems Engineering Team recommends Wright Laboratory continue detailed research into the design of a low cost aircraft defense system similar to the Spec-Net and Det-Net.

Based on the results of this thesis, the GSE-95D Systems Engineering Team also recommends that research not be limited to "smart" expendables. The research presented in this thesis supports the fact that "dumb" expendables, expendables which do not track their target, can effectively be used to eliminate the threat of in inbound, shoulder launched missile. Along with being effective, dumb expendables are also significantly less expensive and less complicated than smart expendables.

8.2 Military Applications

Following detailed design and testing, the system should be implemented on a weapon system such as the C/KC-135. Currently, the basic model C/KC-135 aircraft does not possess an aircraft defense system (flares, chaff, or otherwise). Consequently, the implementation of any of the aircraft defense systems defined in this thesis requires the addition of an entirely new system to the C/KC-135, not simply a modification to an existing defense system. This section describes how such a new aircraft defense system should be integrated into the existing C/KC-135 weapon system.

Certain efforts must be accomplished in order to properly retrofit the C/KC-135 with an aircraft defense system. The retrofitting of an existing C/KC-135 to accommodate a new aircraft defense system should be a coordinated effort with Aeronautical Systems Center (ASC), the USAF Flight Test Center, and the Electronic Defense Office (ASC/LN). The following are the basic steps to modifications required and the proposed points of contact.

1. Procuring test specimen systems
   - ALE-47 flare system (ASC/LN)
   - Detection and tracking system (contractor)

2. Modification of the ALE-47(ASC/MD)
   - Machining of "tube" launcher
   - Attachment of "tube" to swivel plate

3. Development of the expendable

4. Modification of the aircraft test bed for system testing
   (USAF Flight Test Center, ASC/MD)

5. System Testing
6. Analysis and program development (Wright Laboratory)

This is only a recommended list of modification steps and points of contact. Specific steps will depend on the particular aircraft defense system chosen for implementation.

8.3 Civilian Applications

The aircraft defense systems studied in this thesis were evaluated using the trade-off architecture dictated by a military mission and a 1995 budgeting philosophies as related by the Electronic Warfare Division's choice of weighing factors specified in the *Evaluation* step of the System Engineering Process. The solution developed was a low-cost alternative with relatively similar cost and effectiveness weighting factors having the same magnitude.

One may consider a logical spin-off of the aircraft defense systems defined in this thesis would be the integration of these systems into the civil aviation community, particularly the international airlines. Through interviews with individuals associated with the commercial airlines, the GSE-95D Systems Engineering Team discovered that such spin-offs may not be feasible. An anonymous representative of the Chicago district of the Federal Aviation Administration (FAA) indicated in a telephone interview that the cost associated with implementing and supporting such an aircraft defense system on commercial airlines would be prohibitively expensive. This individual's position is supported by an anonymous United Airlines executive who stated, "Anything that adds weight, cost, upkeep, or fear to our business will not be considered unless it is forced on

us by either the FAA or ICAO (International Civil Aviation Organization)." The GSE-95D Systems Engineering Team recommends that Wright Laboratory not attempt to spin-off and/or implement active aircraft defense system in the civilian airline community.

8.4 ACME Development

The ACME simulation is constructed in a modular format so as to facilitate modifications to specific components of the aircraft defense system. For example, the change of SAM guidance logic from LOS to Proportional Navigation (Pro Nav) can be accomplished by modifying a single simulation module defined as *Missile Control.* The modular format of the ACME simulation affords significant flexibility with regard to altering threat SAM dynamics, flight profile of the target aircraft, and design of the expendables. As mentioned in section 2.6, unclassified data used in the ACME simulation can be easily replaced with classified material. Note that modifications involving the use of classified data should only be accomplished on USAF computers authorized for "classified use". The GSE-95D Systems Engineering Team recommends that development of the ACME simulation continue. The ACME simulation's current level of accuracy is sufficient for the level of analysis performed in this thesis. Increasing the accuracy of the ACME via modifications to the aircraft, missile, and expendable models contained within the simulation would provide a tool useful to further development of aircraft defense systems employing kinetic kill mechanisms.

Appendix A: Calculations

Calculation #1. Necessary Deflection Distance

Objective: Calculate the minimum range necessary to deflect the incoming missile

Assumptions:

- missile velocity = 441.96 m/s (1450 ft/s)
- mass missile = 9.967 kg (0.683 slugs)
- Expendable impacts missile at its center of mass perpendicular to the flight path.
- Collision between the missile and expendable is perfectly plastic.
- Ratio of momentums of expendable to the missile ranges from 0 - 0.2

Constants:

lethal sphere radius 30.48 m (100ft)

Variables:

V = velocity
M = mass
MMo = missile momentum
Emo = expendable momentum
Θ_{imp} = missile deflection angle caused by missile expendable collision
DD = distance from aircraft neccesary to deflect missile from lethal sphere around aircraft

Calculations:

Calculation of the momentum of the missile

Momentum = (M)(V)

Before collision: MMo = 9.967 · 441.96

MMo = 4405.02 kg m/s

After collision: MMo = (9.967 + mass expendable) (resultant velocity)

Typical expendable momentum (Spec-Net)

mass = 4.53 kg (0.310559 slugs)
velocity = 152.4 m/s (500 ft/s)

$EMo = 4.53 \cdot 152.4$

$EMo = 690.37\ kg \cdot m/s$

Ratio of momentum of expendable to missile

$Ratio = 690.37\ kg \cdot m/s\ /\ 4405.02\ kg \cdot m/s$

$Ratio = 0.156$ (between 0 and 0.2)

Calculation of resultant angle theta

$\Theta_{imp} = Tan^{-1}$(expendable momentum / new missile momentum)

For Ratio of momentum = 0.156

$\Theta_{imp} = Tan^{-1}(0.156)$

$\Theta_{imp} = 8.87°$

Calculation of distance away from aircraft necessary to deflect missile from aircrafts lethal radius.

$DD = 30.48 / Tan(8.87°)$

$DD = 195.3\ m$

Best case scenario with ratio of momentums equal to 0.2

$\Theta_{imp} = Tan^{-1}(0.2)$ $\Theta_{imp} = 11.3°$

$DD = 30.48 / Tan(11.3)$ $DD = 152.4\ m$ (500 ft)

Solution:

DD can only be a minimum of 152.4 m (500 ft)

Calculation #2. Detonation of Missile

Objective: To calculate the force needed to detonate the stinger missile

Assumptions:

- acceleration needed to detonate missile range 100 - 125 g's (Doherty, 1995)
- missile weight = 97.86 N (22 lbf)
- missile mass = 9.97 kg (0.683 slugs)

Constants:

$1g = 9.81\ m/s^2\ (32.2\ ft/s^2)$

Variables:

a = acceleration
F = force
m = mass

Calculation:

$$F = (m)(a)$$

$$a = [(100 + 125) / 2] \cdot (9.81)$$

$$a = 1103.63\ m/s^2$$

$$m = 9.967\ kg$$

$$F = 9.967 \cdot 1103.63$$

$$F = 10999.88\ N$$

Solutions:

Force = 10999.9 N (2472 lbf)

Calculation #3. Iteration Two Bullet Design

Objective: Calculate the weight, radius (area coverage) and area of drag for the Bullet expendable

Assumptions:

- The bullets are shot from a Vulcan M168 gun
- The bullets are 20mm rounds
- The weight of the bullets is 0.98 N (0.22 lbf) (Franke, 1994)
- The dispersion rate of the M168 gun is 12 mrads = 0.012 rad (Vulcan, 1989:208)
- The drag area of a 20 mm round is 0.0003 m^2 (0.003382 ft^2)

Constants:

Dragarea = 0.0003 m^2
Wbullet = 0.98 N
Θ = angel of dispersion = 12 mrads (0.688°)
Intdist = intercept distance distance from gun to where bullets are supposed to hit the missile threat. = 30.48 m (100 ft)

Variables:

Acov = area covered by the bullets
Radius = radius of area covered by the bullets

Calculation: Radius (area of coverage)

$$\text{Radius} = \text{Intdist} \cdot \text{Tan}\,(\Theta)$$

$$\text{Radius} = 30.48 \cdot \text{Tan}\,(0.012)$$

$$\text{Radius} = 0.366\text{ m } (1.2\text{ ft})$$

$$\text{Acov} = \pi \cdot \text{Radius}^2$$

$$\text{Acov} = \pi \cdot (0.366)^2$$

$$\text{Acov} = 0.42\text{ m}^2\ (4.52\text{ ft}^2)$$

Solutions:

Weight of Bullet = 0.98 N (0.22 lbf)
Area covered by Bullets = 0.42 m^2 (4.52 ft^2)
Drag area of Bullet = 0.0003 m^2 (0.003382 ft^2)

Calculation #4. Iteration Two Spec-Net Design

Objective: Calculate the weight, radius (area coverage) and area of drag for the Spec Net

Assumptions:

- The spectra net is made of Spectra Chord™ dimensions 0.122 cm (0.048 in) x 0.122 cm (0.048 in) (Mangolds, 1995)
- Spectra Chord™ has tensile strength of 978.6 N (220 lbf) (Mangold, 1995)
- Spec-Net occupies a maximum volume of 1837 cm^3 (107 in^3) (volume of expendable casing minus 16.39 cm^3 (6 in^3) for deploying grenade) (Mangolds, 1995)
- Spectra Chord™ is 100% compactible (Mangolds, 1995)
- The mesh size of the net is 22.6 cm^2 (3.5 in^2) (Mangolds, 1995)
- Nets are directly proportional in all parameters to bigger nets (Mangolds, 1995)

Constants:

VFMnet = volume of Foster Miller Inc. Net = 830 cm^3 (50.65 in^3)
RFMnet = radius of Foster Miller Inc. Net = 2.7 m (9 ft)
WFMnet = weight of Foster Miller Inc. Net = 5.16 N (1.16 lbf)
DAFMnet = Drag area of Foster Miller Inc. Net = 0.725 m^2 (7.8 ft^2)

Variables:

Netvol = Volume of net
Radnet = radius of net
Wtotal = total weight of Spec Net
Dragarea = drag area of the Spec Net
Acov = area covered by Spec Net
NumFMnet = number of Foster Miller nets that fit into the available volume

Calculation:

The majority of information for this net is based on the net made by Foster Miller Inc. (Mangolds, 1995).

Netvol = Expvol - Deploying Grenade Volume

Netvol = 1837 cm^3

VFMnet = 830 cm^3

Calculate the number of Foster Miller Nets that fit in the available volume

NumFMnet = Netvol / VFMnet

NumFMnet = 1837 / 830

$NumFMnet = 2$

According to Mr. Mangold, bigger nets have a direct relationship to all of the dimensions of the given Foster Miller net.

i.e. $Newnet = 2 \cdot \text{Foster Miller Net}$

Calculation: Weight

$Wtotal = 2 \cdot WFMnet$

$Wtotal = 2 \cdot (5.16\ N)$

$Wtotal = 10.32\ N$

Calculation: Radius (area of coverage)

$Radnet = 2 \cdot RFMnet$

$Radnet = 2 \cdot 2.7$

$Radnet = 5.49\ m$

$Acov = \pi \cdot Radnet^2$

$Acov = \pi \cdot (5.94)^2$

$Acov = 110.85\ m^2\ (1017.9\ ft^2)$

Calculation: Drag Area

$Dragarea = DAFMnet \cdot 2$

$Dragarea = 2 \cdot 0.725$

$Dragarea = 1.45\ m^2\ (15.6\ ft^2)$

Solutions:

Weight of Net = 10.32 N (2.32 lbf)
Area covered by net = 38 m^2 (1017.9 ft^2)
Drag area of net = 1.45 m^2 (15.6 ft^2)

Calculation #5. Detonation Chord Propogation Speed

Objective: Calculate the necessary propogation speed for a net of radius 3.1 m

Assumptions:

- missile velocity = 441.96 m/s (1450 ft/s)
- net velocity = 152.4 m/s (500 ft/s)
- closing speed = 594.36 m/s (1950 ft/s)
- missile length = 1.52 m (5 ft) (Stinger, 1990:214-217)
- range propogation speeds = 0.30 m/s - 5486.4 m/s (1 ft/s - 18000 ft/s) (Mangolds, 1995)
- net radius = 3.112 m (10.21 ft)
- If 75% of the net detonates by the time the missile gets through, the missile will be destroyed.

Variables:

D = distance
V = velocity
T = time
P = propogation speed

Calculations:

Calculate time for missile to pass any point in space defined as time from when the tip of the missile hits a point to the time the end of missile passes the same point.

$$D = VT$$

$$1.524 \text{ m} = (594.36)(T)$$

$t = 0.0025641$ s (time for 1.52 m missile to pass any point in space)

Calculate radius which will correspond to 75% of nets area

$$\text{Area} = \pi \cdot (\text{radius})^2$$

$$\text{Area} = \pi \cdot (3.112)^2$$

$$\text{Area} = 30.43 \text{ m}^2$$

$$0.75 \cdot (\text{Area}) = 22.82 \text{ m}^2$$

corresponding radius = 2.7 m

Calculate necessary propogation speed

$D = PT$

$P = D/T$

$P = 2.7 / 0.0025641$

$P = 1051.1$ m/s (necessary propogation speed)

Solutions:

$P = 1051.1$ m/s (3448.45 ft/s)

Calculation #6. Iteration Two Det-Net Design

Objective: Calculate the weight, radius (area coverage) and area of drag for the Det-Net

Assumptions:

- The Det-Net is based on the Thunder Road™ net from Foster Miller Inc. The Thunder Road™ net is 417 grain (26.87 g) Detonation Chord™, 30.48 m (100 ft) in diameter and weighs 670 lbs (Mangolds, 1995).
- The Det-Net is made of 18 grain (1.16 g) detchord.
- Det-Net occupies a maximum volume of 1837 cm^3 (107 in^3) (volume of expendable casing minus 16.39 cm^3 (6 in^3) for deploying grenade) (Mangolds, 1995).
- Detonation chord is between 63% - 84% compactible (Mangolds, 1995).
- Due to the small grain size used the Det-Net is assumed to be 83% compactible for this iteration.
- The mesh size of the net is 22.6 cm^2 (3.5 in^2) (Mangolds, 1995).
- Nets are directly proportional in all parameters to bigger nets (Mangolds, 1995).
- The 18 grain Det-Net Detonation Chord™ is equivalent in size to the Spec-Net Spectra Chord™, 0.122 cm x 0.122 cm (Mangolds, 1995).
- The 18 grain Detonation Chord™ has a 0.36 cm (0.142 in) outside diameter.
- The weight of 18 grain Detonation Chord™ is 37.8 N (8.5 lbf) per thousand feet
- The Spec-Net has a weight of 10.32 N (2.32 lbf).
- The Spectra™ material with 0.122 cm x 0.122 cm twine size has a weight of

2.87 lbs per thousand feet.

Constants:

Sthou - weight for thousand feet of Spectra = 12.77 N (2.87 lbf)
Dthou - weight for thousand feet of 18 grain Det Chord = 37.8 N (8.5 lbf)
SpecRad = radius of Iteration 2 Spectra Net = 5.4 m (17.7 ft)
Wspec = weight of Spectra Net = 10.32 N (2.32 lbf)
ODspec = outside diameter of Spectra Chord = 0.122 cm (0.048 in)
ODdet = outside diameter of Detonation Chord = 0.36 cm (0.14 in)
DASpec = drag area of Spectra Net = 1.45m^2 (15.6 ft^2)

Variables:

DetRad = radius of Det-Net
Wtotal = total weight of Det-Net
Dragarea = drag area of the Det-Net
Acov = area covered by Det-Net

Calculation: Radius (area of coverage)

The Det net is assumed to be 83% compactible. The radius of the DetNet will be 83% of the SpecNets radius. This is because they have the same mesh size, and amount of volume to fill. The strands of each net are also roughly equivalent.

$$DetRad = 83\% \cdot SpecRad$$

$$DetRad = 0.83 \cdot 5.4m$$

$$DetRad = 4.482 \text{ m } (15 \text{ ft})$$

$$Acov = \pi \cdot DetRad^2$$

$$Acov = \pi \cdot (4.482)^2$$

$$Acov = 63.11 \text{ m}^2 \ (707 \text{ ft}^2)$$

Calculation: Weight

Proportionalities were used to estimate the weight of the Det Net
The Spectra net has a weight of 2.32 lbs

$$WSpec / Sthou = Wtotal / Dthou$$

$$10.32 \text{ N} / 12.77 \text{ N} = Wtotal / 37.8 \text{ N}$$

$$Wtotal = 30.55 \text{ N } (6.87 \text{ lbf})$$

Calculation: Drag Area

$$Dragarea / ODdet = DAspec / ODspec$$

$$Dragarea = 0.36 \cdot (1.45 / 0.122)$$

$$Dragarea = 4.28 \text{ m}^2 \ (46 \text{ ft}^2)$$

Solutions:

Weight of Net = 30.55 N (6.87 lbf)
Area covered by net = 63.11 m^2 (707 ft^2)
Drag area of net = 4.28 m^2 (46 ft^2)

Calculation #7. Iteration Two Air Bag Design

Objective: Calculate the weight, radius (area coverage) and drag reference area for the Air Bag

Assumptions:

- The Air Bag occupies the volume inside a 7.62 cm (3 in) radius sphere = 1853 cm^3
- The Air Bag is made out of rip stop nylon parachute material
- 50% of the total Air Bag weight is around the base perimeter

Constants:

Tungden = density of tungsten = 19.27 g/cm^3 (0.022 $slug/in^3$) (Handbook: 1980:844)

Ripden = density of parachute material = 0.44g/cm^3 (0.0005 $slugs/in^3$) (Laboratory analysis of rip stop nylon)

Areaconvert = a constant that converts volume of rip stop to area of rip stop:
1 cm^3 = 104.98 cm^2 (Laboratory analysis of rip stop nylon)

Variables:

Mbag = mass of Air Bag
Mtung = mass of tungsten
Mtotal = total mass of Air Bag
Wtotal = weight of parachute material
Vrip = volume of rip stop material
Arip = area of rip stop material
Radbag = radius of the Air Bag
Acov = area covered by the Air Bag

Calculation: Air Bag Weight

Density relationship

(Mbag / Ripden) + (Mtung / Tungden) = 1853 cm^3

Mass Relationship

Mtung = 0.50 · (Mtung + Mbag)

Using two equation above:

Mbag = 797.3 g Mtung = 797.3 g

Mtotal = Mtung + Mbag

$Mtotal = 1478.6$ g (0.101 slugs)

$Wtotal = 1478.6 \cdot 9.81$

$Wtotal = 14.50$ N (3.26 lbf)

Calculation: Radius (area of coverage)

Determime the volume of rip stop nylon available for use in the Air Bag

$Vrip = Mbag \cdot (1 / Ripden)$

$Vrip = 797.3 \cdot (1 / 0.44)$

$Vrip = 1812 \text{ cm}^3$

Determine the square meters of rip stop nylon available for use in the Air Bag

$Arip = Vrip \cdot Areaconvert$

$Arip = 1812 \cdot 104.98$

$Arip = 19.02 \text{ m}^2$

The Air Bag is shaped like a reservoir water tank with the height equal to two times the radius

$Arip = \pi \cdot Radbag^2 + 2\pi \cdot Radbag \cdot 2 \cdot Radbag$

$Radbag = 1.10$ m (3.61 ft)

$Acov = 4 \cdot Radbag^2$ (Looking at the side of the Air Bag)

$Acov = 4.84 \text{ m}^2$ (52.1 ft^2)

Calculation: Drag Area

Side: (in the x and y [forward and horizontal] directions)

$Dragarea = Acov$

$Dragarea = 4.84 \text{ m}^2$

Top: (in the z [vertical] direction)

$$\text{Dragarea} = \pi \cdot \text{Radbag}^2$$

$$\text{Dragarea} = 3.80 \text{ m}^2 \ (41.10 \text{ ft}^2)$$

Solutions:

Weight of Air Bag = 14.50 N (3.26 lbf)
Area covered by Air Bag = 4.84 m^2 (52.1 ft^2)
Drag area of Air Bag (side) = 4.84 m^2 (52.1 ft^2)
Drag area of Air Bag (top) = 3.80 m^2 (41.01 ft^2)

Calculation #8. Iteration Two Cherry Bomb Design

Objective: Calculate the weight, radius (area coverage), drag area, and time of effectiveness for the Iteration Two Cherry Bomb

Assumptions:

- Cherry Bomb occupies a maximum volume of 1853.4 cm^3 (113 in^3) (volume of spherical expendable casing)
- The explosive RDX™ was used for bomb it had best energy per density ratio of all researched explosives (Franke, 1994)
- Steel shrapnel used as kill mechanism
- If a piece of shrapnel hits the missile, the missile is destroyed
- The shrapnel is effective for the time it takes the missile to traverse the length of the expendable.
- Assume a shrapnel to charge weight ratio of 25 : 1
- Shrapnel is assumed to lie on the sphere surface. The sphere surface will be scored such that the desired size of shrapnel pieces will be created upon detonation of the bomb.

Constants:

Steelden = density of steel = 7833.2 kg/m^3 (15.2 slug/ ft^3) (Handbook, 1980:845)
Chargeden = density of RDX™ explosive = 1650.2 kg/m^3 (3.2 slug/ ft^3) (Franke, 1994)
Shrapsize = size of shrapnel = cube 2.54 cm x 2.54 cm x 2.54 cm (1 in x 1 in x 1 in)
Shrapvol = 16.39 cm^3 (1 in^3)
Radcan = radius of expendable sphere = 7.62 cm (3 in)
Cvel = closing velocity of missile and expendable = 594.4 m/s (1950 ft/s)
Lmissile = length of missile = 1.53 m (5 ft)
Wsteel = weight of steel = 111.2 N (25 lbf)
Wcharge = weight of charge 4.45 N (1 lbf)
Lside = length of one side of shrapnel = 2.54 cm (1 in)
E = Gurny constant for RDX™ explosive = 2834.6 m/s (9300 ft/s)
MC = Mass of Steel to Mass of Charge Ratio = 25
Time = Time expendable is effective (Time it takes for bomb to explode) 0.01 s (Franke, 1994)

Variables:

Dragarea = drag area for shrapnel pieces
Wbomb = weight of bomb
Vshrap = velocity of shrapnel pieces
Radcov = radius of circle of the area covered
Acov = area of coverage of the bomb

Calculation: Weight

$Wbomb = Wsteel + Wcharge$ $Wbomb = 111.2\ N + 4.5\ N$

$Wbomb = 115.7\ N$

Calculation: Time Effective

$Time = 0.01s$

Calculation: Radius (area of coverage)

For a Spherical Casing the velocity of fragments upon explosion of the charge is the equation:

$Vshrap = E\ (MC + 3/5)^{-1/2}$ (Franke, 1994)

$Vshrap = 2834.6 \cdot (25 + 3/5)^{-1/2}$

$Vshrap = 560.2\ m/s$

$Radcov = Vshrap \cdot Time$

$Radcov = 560.2 \cdot 0.01$

$Radcov = 5.602\ m$

$Acov = \pi \cdot Radcov^2$

$Acov = 98.6\ m^2$ ($1061.2\ ft^2$)

Calculation: Drag Area

$Dragarea = Lside \cdot Lside$

$Dragarea = 2.54 \cdot 2.54$

$Dragarea = 6.45\ cm^2$

Solutions:

Weight of Cherry Bomb = 115.7 N (26 lbf)
Area covered by Cherry Bomb = $98.6\ m^2$ ($1061.2\ ft^2$)
Drag area of Shrapnel = $6.45\ cm^2$ ($1\ in^2$)

Calculation #9. Bullet Canister Design

Objective: Calculate the size and weight of the expendable Bullet Canister

Assumptions:

- Volume matches that of a standard flare bucket = 5735.4 cm^3 (350 in^3)
- "Bullet shape" with the length equal to three times the diameter
- Shell made out of 0.3175 cm (0.125 in) plate aluminum

Constants:

ρ = density of aluminum = 2.712 g/cm^3 (0.098 lbf/in^3) (Parker,1967:68)

Variables:

Rad = canister radius
Dia = canister diameter
Len = canister lenght
Vcyl = volume of cylinder
Vsemi = volume of semi-sphere
Vol = canister volume
Abot = bottom surface area of canister
Acyl = cylinder surface area
Asemi = semi-sphere surface area
Area = total surfcae area of canister
Volalum = volume of aluminum
Mcan = mass of canister
Wtotal = canister weight

Calculations:

Calculation of the canister size

$$Vcyl = \pi \cdot Rad^2 \cdot Len$$

$$Vsemi = 2\pi \cdot Rad^3 / 3$$

$$Lenght = 6 \cdot Rad$$

Volumes of the cylinder and semi-sphere equate to total volume - solve for radius

$$Vcyl + Vsemi = 5735.45 \text{ cm}^3$$

Radius = 6.5 cm (2.56 in)

Calculation of the canister weight

$Abot = \pi \cdot Rad^2$

$Abot = 132.7\ cm^2\ \ (20.57\ in^2)$

$Acyl = 2\pi \cdot Rad \cdot Len$

$Acyl = 1592.8\ cm^2\ \ (246.88\ in^2)$

$Asemi = 2\pi \cdot Rad^2$

$Asemi = 265.5\ cm^2\ (41.15\ in^2)$

$Area = Abot + Acyl + Asemi$

$Area = 1990.96\ cm^2\ \ (308.60\ in^2)$

$Volalum = Area \cdot 0.03175$

$Volalaum = 632.13\ cm^3\ \ (385.75\ in^3)$

$Mcan = Volalum \cdot \rho$

$Mcan = 1720\ g\ (0.117\ slugs)$

$Wtotal = 1.72 \cdot 9.81$

$Wtotal = 16.86\ N\ \ (3.78\ lbf)$

Solutions:

Radius = 6.5 cm (2.56 in)
Diameter = 13 cm (5.12)
Lenght = 39 cm (15.4 in)
Weight = 16.86 N (3.78 lbf)

Calculation #10. Iteration Three Spec-Net Design

Objective: Calculate the weight, radius (area coverage) and area of drag for the Spec-Net

Assumptions:

- The Spec-Net is made of spectra chord dimensions = 0.15875 cm (0.0625 in) x 0.3175 cm (0.125 in)
- Spectra Chord™ has tensile strength of 6672.3 N (1500 lbf)
- Spec-Net occupies a maximum volume of 5637.5 cm^3 (344 in^3) (volume of expendable casing minus 16.39 cm^3 (6 in^3) for deploying grenade)
- 30% of total Spec-Net weight is around the outer perimeter
- The outer perimeter weight is equal to the weight of tungsten in the net
- Spectra Chord™ is 100% compactible
- The mesh size of the net is set small enough to guarantee two strands impacting the head of the Stinger missile

Constants:

Carea = cross sectional area of Spectra Chord™ = 0.05 cm^2
Tungden = density of tungsten = 19.27 g/cm^3 (0.022 slug/in^3) (Handbook, 1980:844)
Specden = density of Spectra Chord™ = 0.655 g/cm^3 (0.0007 slug/in^3) (Mangolds, 1995)
Mesh = mesh size of net = 6.35 cm (2.5 in) (from diameter of Stinger missile head 6.604 cm (2.6 in) (Stinger, 1990:214-217))

Variables:

Mspec = mass of Spectra Chord™
Mtung = mass of tungsten
Mtotal = total mass of Spec-Net
Wtotal = total weight of Spec-Net
Length = length of Spectra Chord™ in Spec-Net
Radnet = radius of Spec-Net
Side = side of square Spec-Net
Grid = number of grid spaces along the side of a Spec-Net
Dragarea = drag area of the Spec-Net
Acov = area covered by Spec-Net

Calculation: Weight of Spec-Net

Density relationship

(Mspec / Specden) + (Mtung / Tungden) = 5637.5 cm^3

Mass Relationship

$$Mtung = 0.30 \cdot (Mtung + Mspec)$$

Using previous two equations:

$$Mspec = 3640 \text{ g}$$

$$Mtung = 1560 \text{ g}$$

$$Mtotal = Mtung + Mspec$$

$$Mtotal = 5200 \cdot 0.356$$

$$Wtotal = 5200 \cdot 9.81$$

$$Wtotal = 51.01 \text{ N } (11.5 \text{ lbf})$$

Calculation: Radius (area of coverage)

The volume and cross sectional area of Spec-Net determines the length of chord available of the Spec-Net.

$$Mspec / Specden = Carea \cdot Length$$

$$3640 / 0.655 = 0.05 \cdot Length$$

$$Length = 1102 \text{ m}$$

Calculate a square net from the available length of chore considering mesh size

$$Length = 2 \cdot Mesh \cdot Grid \cdot (Grid + 1)$$

$$Side = Mesh \cdot Grid$$

$$1102 = 2 \cdot 0.06985 \cdot (Grid^2 + Grid)$$

$$Grid = 88.33$$

$$Side = 6.17 \text{ m}$$

Convert the square net to a round net by equating surface areas

$$Side^2 = \pi \cdot Radnet^2$$

$$6.17^2 = \pi \cdot Radnet^2$$

$$Radnet = 3.48 \text{ m } (11.417 \text{ ft})$$

$$Acov = \pi \cdot Radnet^2$$

$$Acov = 38.07 \text{ m}^2$$

Calculation: Drag Area

$$Dragarea = Length \cdot 0.003175$$

$$Dragarea = 3.5 \text{ m}^2$$

Solutions:

Weight of Net = 51.01 N
Area covered by net = 38.07 m^2
Drag area of net = 3.5 m^2

Calculation #11. Iteration Three Det-Net Design

Objective: Calculate the weight, radius (area coverage) and area of drag for the Det-Net

Assumptions:

- The detonation net is made out of 27.5 grain size detonation cord for a factor of safety of 10%
- Det-Net occupies a maximum volume of 5637.5 cm^3 (344 in^3) (volume of expendable casing minus 16.39 cm^3 (6 in^3) for deploying grenade)
- 30% of total Det-Net weight is around the outer perimeter
- Detonation Cord™ is 75% compactable
- The mesh size of the net is set small enough to guarantee two strands impacting the head of the Stinger missile

Constants:

Carea = cross sectional area of Detonation Chord™ = 0.025 cm^2

Tungden = density of tungsten = 19.27 g/cm^3 (0.02 $slug/in^3$) (Handbook, 1980:844)

Detden = density of Spectra Chord™ = 0.81 g/cm^3 (0.0091 $slug/in^3$) (Mangolds, 1995)

Mesh = mesh size of net = 6.35 cm (2.5 in) (from diameter of Stinger missile head 6.604 cm (2.6 in) (Stinger, 1990:214-217))

Variables:

Mdet = mass of Detonation Chord™

Mtung = mass of tungsten

Mtotal = total mass of Det-Net

Wtotal = total weight of Det-Net

Length = length of detonation chord in Det-Net

Radnet = radius of Det-Net

Side = side of square Det-Net

Grid = number of grid spaces along the side of a Det-Net

Dragarea = drag area of the Det-Net

Acov = area covered by Det-Net

Calculation: Weight of Det-Net

Density relationship

$$(Mdet / Detden) + (Mtung / Tungden) = 5637.5 \text{ cm}^3$$

Mass Relationship

$$Mtung = 0.30 \cdot (Mtung + Mdet)$$

Using previous two equations:

Mdet = 3380 g   Mtung = 1450 g

Mtotal = Mtung + Mdet

Mtotal = 4830 g (.331 slugs)

Wtotal = $4830 \cdot 9.81$

Wtotal = 47.38 N (10.65 lbf)

Calculation: Radius (area of coverage)

The volume and cross sectional area of Det-Net determines the length of chord available of the Det-Net.

Mdet/ Detden = Carea $\cdot$ Length

$3380 / 0.81 = 0.025 \cdot$ Length

Length = 2226 m (7304 ft)

Detonation cord is only 75% compactalbe

Lenght = Length $\cdot$ 0.75

Lenght = 1669 m (5476 ft)

Calculate a square net from the available length of chore considering mesh size

Length = $2 \cdot$ Mesh $\cdot$ Grid $\cdot$ (Grid + 1)

Side = Mesh $\cdot$ Grid

$1669 = 2 \cdot 0.06985 \cdot (\text{Grid}^2 + \text{Grid})$

Grid = 112

Side = 7.69 m (25.2 ft)

Convert the square net to a round net by equating surface areas

$$\text{Side}^2 = \pi \cdot \text{Radnet}^2$$

$$7.69^2 = \pi \cdot \text{Radnet}^2$$

$$\text{Radnet} = 4.34 \text{ m } (14.24 \text{ ft})$$

$$\text{Acov} = \pi \cdot \text{Radnet}^2$$

$$\text{Acov} = 59.17 \text{ m}^2 \ \ (636.96 \text{ ft}^2)$$

Calculation: Drag Area

$$\text{Dragarea} = \text{Length} \cdot 0.001786 \text{ m}$$

$$\text{Dragarea} = 2.97 \text{ m}^2 \ \ (31.97 \text{ ft}^2)$$

Solutions:

Weight of Net = 47.38 N (10.65 lbf)
Area covered by net = 59.17 m^2 (636.96 ft^2)
Drag area of net = 2.97 m^2 (31.97 ft^2)

Calculation #12. Iteration Three Cherry Bomb Design

Objective: Determine the weight, area of coverage, time effective, and drag area for the Cherry Bomb

Assumptions:

- Cherry Bomb occupies a maximum volume of 5653.9 cm^3 (350 in^3) (volume of expendable casing)
- The explosive RDX™ is used for Cherry Bomb because it has a very high energy per density ratio.
- Steel shrapnel used as kill mechanism
- If a piece of shrapnel hits the missile, the missile is destroyed
- The shrapnel is effective for the time it takes the missile to traverse the length of the expendable.

Constants:

Steelden = density of steel = 7833.2 kg/m^3 (15.2 slug/ ft^3) (Handbook, 1980:845)
Chargeden = density of RDX™ explosive = 1650.2 kg/m^3 (3.2 slug/ ft^3) (Franke, 1994)
Shrapsize = size of shrapnel = cube 0.3175 cm x 0.3175 cm x 0.3175 cm (0.125 x 0.125 in x 0.125 in)
Shrapvol = 0.032 cm^3 (0.002 in^3)
Radcan = radius of expendable cannister = 6.5 cm (2.56 in)
Lcan = length of expendable cannister = 38.1 cm (15 in)
Layers = number of layers of shrapnel = 8 (8 layers is choses to ensure that upon detonation, the circle of coverage created by the detonating shrapnel is filled with shrapnel by the layers)
Mdiam = diameter of the missile head = 7 cm (2.76 in)
Cvel = closing velocity of missile and expendable = 594.4 m/s (1950 ft/s)
Lmissile = length of missile = 1.53 m (5 ft)

Variables:

Wbomb = weight of bomb
Mbomb = Mass of bomb
Msteel = Mass of steel
Mcharge = Mass of charge
Ccan = circumference of expendable cannister
Shraprow = number of shrapnel pieces in a row
row = number of rows of shrapnel
Tshrap = total number of shrapnel pieces
Stvol = volume of steel
Chvol = volume of charge
Ccov = circumference of coverage area
Radcov = radius of circle of the area covered
Time = time expendable is effective

Calculation: Weight

We want the shrapnel to ring the length and circumference of the cannister to ensure an even radius is covered by the shrapnel upon explosion

$Ccan = 2 \cdot \pi \cdot Radcan$ $Ccan = 2 \cdot \pi \cdot 6.5$

$Ccan = 40.84$ cm

Shraprow = Ccan / length of one side of shrapnel

$Shraprow = 40.84 / 0.3175$

$Shraprow = 128$

row = Lcan / length of one side of shrapnel

$row = 38.1 / 0.3175$

$row = 120$

$Tshrap = Shraprow \cdot row \cdot Layers$

$Tshrap = 128 \cdot 120 \cdot 8$

$Tshrap = 122880$

$Stvol = Tshrap \cdot Shrapvol$ $Stvol = 122880 \cdot 0.032$

$Stvol = 3932.2\ cm^3$

$Msteel = Steelden \cdot Stvol$ $Msteel = 7833.2 \cdot 0.0039322$

$Msteel = 30.8$ kg

$Chvol = Totalvolume - Stvol$

$Chvol = 5653.9 - 3932.2$

$Chvol = 1721.7\ cm^3 = 0.0017217\ m^3$

$Mcharge = Chvol \cdot Chargeden$ $Mcharge = 0.0017217 \cdot 1650.2$

$Mcharge = 2.84$ kg

$Mbomb = Mcharge + Msteel$ $\qquad$ $Mbomb = 2.84 + 30.8$

$Mbomb = 33.6$ kg

$Wbomb = Mbomb \cdot gravity$ $\qquad$ $Wbomb = 33.6 \cdot 9.81$

$Wbomb = 330$ N (74 lbf)

Calculate: Area of coverage

The circumference of the circle covered by the exploding shrapnel equals the diameter of the missile times the number of spaces between the shrapnel pieces (this ensures that the missile cannot slip through a space on the circle of coverage) plus the number of shrapnel pieces times their lengths.

$Ccov = (Mdiam \cdot Shraprow) + (\text{length of shrapnel} \cdot Shraprow)$

$Ccov = (7 \cdot 128) + (0.3175 \cdot 128)$

$Ccov = 936.6$ cm

$Radcov = Ccov / 2 \cdot \pi$

$Radcov = 149$ cm (4.89 ft)

$Acov = \pi \cdot Radcov^2$

$Acov = 69750\ cm^2$ ($75\ ft^2$)

Calculate: Time effective

The Cherry Bomb is assumed to be effective for the time it takes the missile to travel the length of the expendable

$Time = Lcan + Lmissile / Cvel$

$Time = (0.381 + 1.53) / 594.4$

$Time = 0.003$ s

Calculate: Drag area

Drag area of the deployed expendable is the drag area of the pieces of shrapnel

Drag area = $0.3175 \cdot 0.3175$

Drag area = $0.1\ cm^2$

Solutions:
Weight of Cherry Bomb without cannister = 330 N (74 lbf)
Area Covered by Cherry Bomb = $69750\ cm^2$ ($75\ ft^2$)
Time Cherry Bomb effective = 0.003 s
Drag area = $0.1\ cm^2$ ($0.0156\ in^2$)

Calculation #13. Spherical Container Equations of Motion

Objective: To calculate the equations of motion for the spherical containter in which the expendables in Iteration Two are encased

Assumptions:

- The mass of the spherical container and expendable contents are homogenous.

Variables:

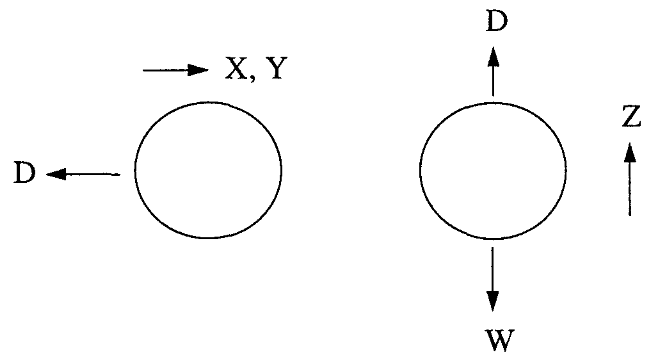
D = Drag Force	m = Mass of sphere and expendable
V = Velocity	S = Drag reference area
a = Acceleration	W = Weight = m·(acceleration due to gravity)
C_d = Drag Coefficient	x' = First derivative of position (velocity)
ρ = Ambient air density	x'' = Second derivative of position (acceleration)

For Iteration Two:

m = 1.6 kg (empty, need to add mass of expendable also)
$\rho = 1.225\ kg/m^3$
$C_d = .15$ (Hoerner, 1958: 16-16)
$S = 1.27\ cm^2$

Calculations:

Free-Body Diagram of Spherical Container



Note that the first free-body diagram only describes forces in the forward (X) and Lateral (Y) directions only. The second free-body diagram only describes forces in the vertical (Z) direction.

Drag Force Calculation

$$D = C_d \cdot (1/2) \cdot \rho \cdot V^2 \cdot S$$

Equation of Motion For X and Y (Forward and Lateral) Directions:

$$-D = m \cdot a$$

Equation of Motion For Z (Vertical) Direction:

$$D - W = m \cdot a$$

Solutions:

Equation of Motion For X and Y (Forward and Lateral) Directions:

$$-(C_d \cdot (1/2) \cdot \rho \cdot (x')^2 \cdot S) = m \cdot x''$$

Equation of Motion For Z (Vertical) Direction:

$$(C_d \cdot (1/2) \cdot \rho \cdot (x')^2 \cdot S) - W = m \cdot x''$$

Calculation #14. Expendable Equations of Motion

Objective: To calculate the equations of motion for the expendables in Itteration

Assumptions:

- The Air Bag is rigid as it moves through the air.
- The majority of the profile drag on the nets is skin friction drag and not pressure drag (drag due to separation).
- The velocity vector of each net is always perpendicular to the net face.
- The velocity vector of each fragment of the Cherry Bomb is perpendicular to face of the flat plat (Cherry Bomb fragments are modeled as flat plates)
- The velocity vector of the Bullet is always perpendicular to the circular cross-sectional area of the Bullet
- Fragments from the Cherry Bomb have a cross sectional area of approximately 7.5 cm^2 (1 in^2)
- Ambient conditions are considered seal level standard.

Constants:

ρ = 1.225 kg/m^3 (.002378 $slugs/ft^3$)

Variables:

D = Drag Force	V = Velocity
m = Mass	S = Drag reference area
a = Acceleration	W = Weight = m·(acceleration due to gravity)
C_d = Drag Coefficient	x' = First derivative of position (velocity)
ρ = Ambient air density	x'' = Second derivative of position (acceleration)

Calculations:

All of the expendable equations of motion have the same basic form based on the same free-body diagram as described for the spherical container in which the expendables are encased in Iteration Two. The forward (X) and Lateral (Y) equations of motions are based on some cross-sectional shape (in this case, shown as a circle but, obviously different for each expendable) moving through the air impeaded only by the force of drag. The vertical (Z) equation of motion is based on some cross-sectional shape (in this case, shown as a circle but, obviously different for each expendable), moving through the air impeaded only by the forces of drag and gravity. The resulting equations of forward and lateral motion and the equation for vertical motion is the same as those defined for the spherical container.

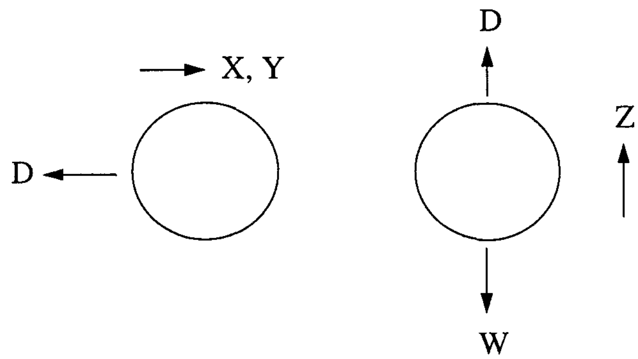
Equation of Motion For X and Y (Forward and Lateral) Directions:

$$-(C_d \cdot (1/2) \cdot \rho \cdot (x')^2 \cdot S) = m \cdot x''$$

Equation of Motion For Z (Vertical) Direction:

$$(C_d \cdot (1/2) \cdot \rho \cdot (x')^2 \cdot S) - W = m \cdot x''$$

The drag force is different for each of the equations of motion. The drag force for a particular direction of motion (forward, lateral, or vertical) is based on the cross-sectional area defined for that direction of motion (drag reference area, S). For example, the Air Bag is modeled as a cylinder in the forward and lateral directions. The drag force is based on the drag force on a cylinder having the same forward and lateral cross-sectional areas as does the Air Bag. In contrast, the vertical direction of the Air Bag's motion is modeled as a flat plate. Consequently, the drag force in the vertical direction is based on the drag force on a flat plate having the same vertical cross-sectional area as does the Air Bag.



Air Bag

As already described, the forward and lateral directions of motion are calculated assuming the Air Bag is modeled as a cylinder. The drag in the vertical direction of motion is calculated assuming the Air Bag is modeled as a flat plate (Hoerner, 1958:3-24). The drag coefficients are based on the shape on which a particular direction is modeled. For example, the vertical drag coefficient is based on a flat plate moving through the air. The forward and lateral drag coefficients are based on a cylinder moving through the air (long

axis of the cylinder perpendicular to the velocity vector) (Hoerner, 1958:3-17).

$C_{d\ vertical} = 1.1$ | $S_{vertical} = 3.8\ m^2$ | $m = 1.47$ kg

$C_{d\ forward} = C_{d\ lateral} = 1.1$ | $S_{forward} = S_{lateral} = 4.8\ m^2$

Spec-Net & Det-Net

Each net is modeled as flat plate. The area of the flat plate, defined as the variable "S", is equal to the area of the net face minus the area of the meshes (holes in the net). Based on the calculated direction of the net's velocity vector relative to the inertial reference frame (keep in mind the assumption that the velocity vector of the net is always perpendicular to the net face), the projections of the area of the net face onto planes perpendicular to the X, Y, and Z inertial axes are calculated. These three projected areas are then used as the drag reference areas used to calculate the drag force in the appropriate X, Y, or Z direction. The drag coefficents for the net designs are taken from the sixth edition of the Engineer in Training Review Manual (Lindeburg, 1982:4-27).

Iteration Two:

Spec-Net:	$C_d = 1.16$	$S = 1.5\ m^2$	$m = 1.1$ kg
Det-Net:	$C_d = 1.16$	$S = 4.3\ m^2$	$m = 3.1$ kg

Iteration Three:

Spec-Net:	$C_d = 1.16$	$S = 3.5\ m^2$	$m = 5.2$ kg
Det-Net:	$C_d = 1.16$	$S = 2.2\ m^2$	$m = 3.3$ kg

Cherry Bomb

Upon explosion of the sphere, the fragments of the Cherry Bomb are modeled as a 7.5 cm^2 (1 in^2) flat plate. As with the net, the drag reference area of each Cherry Bomb fragments for a particular direction (X, Y, or Z inertial) is determined by calculating the projection of the fragment face onto a plane perpendicular to that particular inertial direction. The drag coefficient for the Cherry Bomb fragments are taken from Fluid-Dynamic Drag: Practical Information on Aerodynamic Drag and Hydrodynamic Resistance (Franke, 1994).

Iteration Two:

$C_d = 0.38$ | $S = 6.5\ cm^2$ | $m = 0.13$ kg

Iteration Three:

$C_d = 0.38$ $S = 0.1\ cm^2$ $m = 0.2\ g$

Bullet

Sufficient information is available to model the Bullet as a bullet. The drag coefficient for the Bullet is taken from Fluid-Dynamic Drag: Practical Information on Aerodynamic Drag and Hydrodynamic Resistance (Franke, 1994).

$C_d = 0.38$ $S = 3.1\ cm^2$ $m = 0.10\ kg$

Calculation #15. Bullet Canister Equations of Motion

Objective: To calculate the equations of motion for the Bullet Canister in which the expendables in Iteration Three are encased

Assumptions:

- The mass of the Bullet Canister and expendable contents are homogenous.
- The Bullet Canister's velocity vector is normal to its circular cross-section

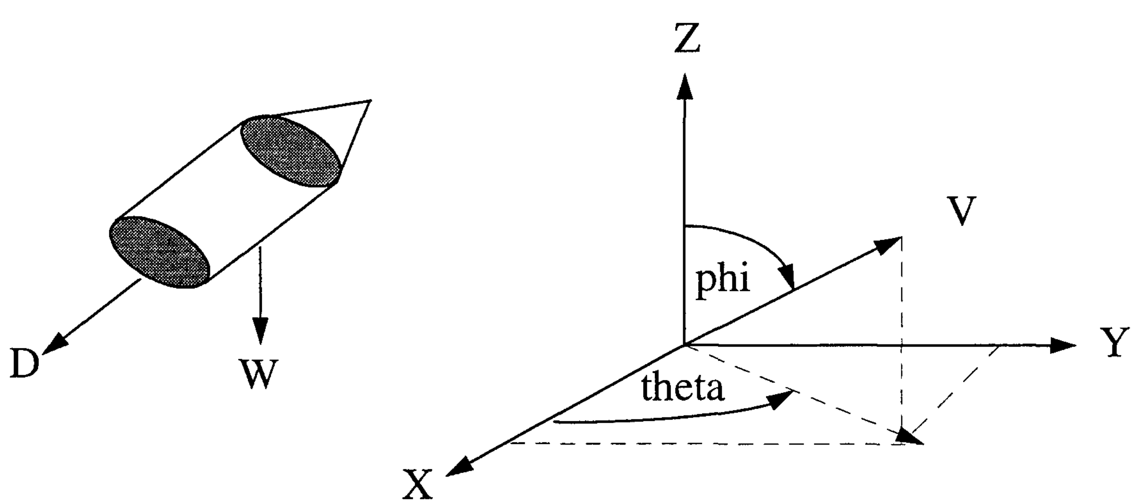
Variables:

D = Drag Force	m = Mass of bullet cansiter
V = Velocity	S = Drag reference area
a = Acceleration	W = Weight = m·(acceleration due to gravity)
C_d = Drag Coefficient	x', y', z' = First derivative of position (velocity)
ρ = Ambient air density	x'', y'', z'' = Second derivative of position (acceleration)

For Iteration Two:

m = 1.6 kg (empty, need to add mass of expendable also)
$\rho = 1.225\ kg/m^3$
$C_d = .22$ (Hoerner, 1958: 16-14)
$S = 132\ cm^2$

Calculations:



Equations of motion are developed for the Bullet Canister based on the free-body diagram displayed above. The drag force is calculated using the Bullet Canister's resultant velocity, V. It is then subdivided into the X, Y, and Z inertial components. The

following equations of motion for the Bullet Canister are then numerically integrated in order to determine the Bullet Canister's trajectory.

Drag Force Calculation

$$D = C_d \cdot (1/2) \cdot \rho \cdot V^2 \cdot S$$

Equation of Motion For X (Forward) Direction:

$$-D_x \cdot \sin(\phi) \cdot \cos(\theta) = m \cdot a_x$$

$$(C_d \cdot (1/2) \cdot \rho \cdot (x')^2 \cdot S_x) = m \cdot x''$$

Where $S_x = S \cdot \sin(\phi) \cdot \cos(\theta)$ (Projected drag reference area normal to x [forward] direction)

Equation of Motion For X (Forward) Direction:

$$-D \cdot \sin(\phi) \cdot \sin(\theta) = m \cdot a_y$$

$$-(C_d \cdot (1/2) \cdot \rho \cdot (y')^2 \cdot S_y) \cdot \sin(\phi) \cdot \sin(\theta) = m \cdot y''$$

Where $S_y = S \cdot \sin(\phi) \cdot \sin(\theta)$ (Projected drag reference area normal to y [lateral] direction)

Equation of Motion For Z (Vertical) Direction:

$$D \cdot \cos(\phi) - W = m \cdot a_z$$

$$(C_d \cdot (1/2) \cdot \rho \cdot (z')^2 \cdot S_z) \cdot \cos(\phi) - W = m \cdot z''$$

Where $S_z = S \cdot \cos(\phi)$ (Projected drag reference area normal to z [vertical] direction)

Appendix B: Sample Model Calculations

This appendix presents sample calculations of the models presented in Chapter V for the following aircraft defense system.

Detector: Composite #1

Tracker: None

Launcher: Explosive - ALE 47 Control System

Expendable: Spec-Net

Effectiveness Model

Probability of Kill:

The ACME simulation is run 100 times for the sample scenario. The resulting probability of kill is the following:

PK: 0

Passivity:

Passivity: 100

False Alarm Rate:

False Alarm Rate: 30

The following table summarizes the results of the Effectiveness Model sample calculations.

Measurable	Raw Score
PK	0
Passivity (1-100)	100
False Alarm Rate (1-100)	30

Environmental Impact Model

The Spec-Net is known to be made out of Spectra™. This is a type of kevlar wire that is safe to human touch and thus does not result in being rated as harmful. The explosive charge that releases the expendable may present some harmful agents immediately after deployment, however, these chemicals will dissipate into insignificant levels long before contact with humans, animal or plant life.

Harmful Pollutant Effects:

The following list presents the primary materials which compose the expendable

1. Spectra
2. Lead
3. Aluminum
4. Explosive Charge

Based on the CRC Practicle Handbook of Environmental Control, the following Harmful Pollutant Effects rating is given to this aircraft defense system.

Harmful Pollutant Effects Rating: 100

Collateral Damage:

Impact Temperature: 25° C

Kinetic Energy:

Kinetic Energy = (.5)(mass)(Velocity $_{Terminal}$)^2

Expendable mass: 0.033 kg
Acceleration due to gravity (g): 9.81 m/sec^2
Drag Coefficient (C_d): 1.16
Drag Reference Area (S): 0.232 m^2
Ambient Air Density (ρ): 1.29 kg/m^3

$$\text{Velocity}_{\text{Terminal}} = \sqrt{\frac{2 \cdot g \cdot (\text{mass})}{C_d \cdot \rho \cdot S}}$$

$$\text{Velocity}_{\text{Terminal}} = 1.37 \text{ m/s}$$

Kinetic Energy: 0.188 N/m

The following table summarizes the results of the Environmental Impact Model sample calculations.

Measurable	Raw Score
Harmful Pollutant Effect (1-100)	100
Impact Temperature (deg C)	25
Kinetic Energy (N/m)	0.188

Impact on Aircraft Model

Displacement:

Control Panel:

3146 cm^3 (192 in^3) available in cockpit on left lower subpanel. Actual control panel modeled after ALE 47 panel is 98.32 cm^3 (6 in^3)

98.32/3146=.03125

Percent of total volume: .03125

Detector:

45359 cm^3 (2768 in^3) available in normal radome. Infinite availability in underside mounting. Actual detector hardware is approximately 22679 cm^3 (1384 in^3) when packaged as a square component.

22679/45359 = .52

Percent of total volume: .52

Launcher:

Essentially infinite room is available on bottom side mounting. In side availability is less than 5.66 m^3 (200 ft^3). Launcher based on Cobra helicopter style turret with total cubic displacement of less than 2.04 m^3 (72 ft^3) to include ammunition feed. (Bell, 1994:434-436)

2.04/5.66 = .35

Percent of total volume: .35

Expendable:
Calculation to be included in launcher:

Total percentage of available space used (worst case): 52% (Detector)

Weight:

Control Panel: 10.24 N (2.3 lbsf)
Detector: 106.8 N (24 lbsf)
Launcher: 2536.5 N (570 lbsf) (Austin, 1995)
Expendable: 26.7 N (6.0 lbsf)

Total Weight: 2680.24 N (596.3 lbs)

Interfaces Required:

Control Panel: DC Power and 1553 Bus Interconnect
Detector: 1553 Bus Interconnect (GPS/INS) and AC Power
Launcher: 1553 Bus Interconnect
Expendable: None

Total number of interfaces required: 5

Power Required:

Control Panel: 28V DC Power
Detector: 115V AC Power
Launcher: 115V AC Power/28 V DC Power
Expendable: None

Available Aircraft Power: 28V DC Power, 115/200 V AC Power (400 Hz)

Available excess voltage (worst case): 0 V AC / 172 V DC

CG Travel:

Assume: Additional 2700 N (600 lbsf) in furthest aft section additional 90 N (20 lbsf) in cockpit

Calculated CG (Fully fueled) 30.9% Mean Aerodynamic Chord (MAC) aft

0.3 % more aft than nominal

Available travel : 18% MAC to 35% MAC

Calculation = .3/17=.0176 %

Total CG travel: .0176% aft

The following table summarizes the results of the Impact on Aircraft Model sample calculations.

Measurable	Raw Score
Displacement (% Total Volume)	
Conrol Panel	3.13
Detector	52
Launcher	35
Expendable	
Worst Case Volume Consumed	52
Weight (Newtons)	
Conrol Panel	10.24
Detector	106.8
Launcher	2536.5
Expendable	26.7
Total	2680.24
Interfaces Required (Number)	
Conrol Panel	2
Detector	2
Launcher	1
Expendable	0
Total	5
Power Required (Volts AC Volts DC)	
Conrol Panel	0 / 28
Detector	115 / 0
Launcher	115 / 28
Expendable	0 / 0
Worst Case Excess Voltage	0 / 172
CG Travel (% MAC)	.3 Aft

Impact on Mission Model

Range Degradation:

Assume a profile drag increase of 0.1% , no thrust decrease, weight increase of 2670 N (600 lbsf), max loading, and best CG management.

Range Degradation: 166.7 km (90 NM)

Endurance Degradation:

Same assumptions as defined for the Range Degredation

Endurance Degrade: 20 min.

System Isolation:

No tap into primary aircraft hydraulic power

System Isolation: YES

On Time Takeoff Prevention:

No tap into primary aircraft hydraulic power

On Time Takeoff Prevention: NO

The following table summarizes the results of the Impact on Mission Model sample calculations.

Measurable	Raw Score
Range Degrade (km)	166.7
Endurance Degrade (min)	20
System Isolation	YES
On Time Prevent	NO

Installation Requirements Model

Man Hours for modification:(Structural/Integration):

Man Hours (Structural/Integration): 1100/3700

Personnel Requirements:

Requirement: 3 per wing

The following table summarizes the results of the Installation Requirements Model sample

calculations.

Measurable	Raw Score
Man Hours for Mod (Structural/Integration)	1100/3700
Personnel Requirements	3 per wing

Life Cycle Cost Model

Note that all cost values in this model have the units of 95 year U.S. dollars.

RDT&E Cost:

Total RDT&E Cost = $4,100,000

Acquisition Cost:

AAR-47 = $80,000

ALE-47 = $32,000

Each Expendable = $200

Total Acquisition Cost = $92,200

Operations Cost:

Maintenance Rank = 8

Cops2 = $100,000 - (8)($10,000) = $20,000

Assume no spares

Energy Cost = $200

Total Operations Cost= $20,000 + $200 + 0 + 0 + 0 = $20,200

Disposal Cost:

Total Disposal Cost = (.01)($4,100,000 + $92,200 + $20,200) = $42,124

Total Life Cycle Cost= $4,100,000 + $92,200 + $20,200 + $42,124 = $4,254,524

The following table summarizes the results of the Life Cycle Cost model sample calculations.

Measurable	Raw Score
RDT&E Cost	$4,100,000
Acquisition Cost	$92,200
Operations Cost	$20,200
Disposal Cost	$42,124
Life Cycle Cost	$4,254,524

Maintenance Requirements Model

Maintenance Rating (MR) = (IMR - H - F - E - SH - T)(10)

Initial Maintenance Reliability (IMR):

R	1.000 - 9.600	0.959 - 0.920	0.919 - 0.880	0.879 - 0.840	0.839 - 0.800	0.790 - 0.000
IMR	10	9	6	4	2	0

$R = e^{-ts}$

$s = sf/1000$

$sf = x + y + z$

$x = .6$

$y = .04$

$z = .3$

Where:

t - average sortie duration (ASD), typically 4.3 hrs

sf - system failure rate

x - Number of Detection & Tracking System Failures per 1000 hrs

y - Number of Launch System failures per 1000 hrs

z - Number Expendable failures per 1000 hrs

$sf = .6 + .04 + .3$

$s = .00094$

$t = 4.3$ hrs

$R = .96$

IMR = 9

Man-hours per Week (H):

Man Hrs	0.0 - 5.0	5.1 - 10.0	10.1 - 15.0	15.1 - 20.0
H	0	1	2	3

H = 1

Facilities (F):

F = 0

Equipment (E):

E = 0

Special Handling (SH):

SH = 0

Testing (T):

T = T1 + T2

T1 = 1

T2 = 0

System Maintenance Rating:

MR = (10 - 1 - 0 - 0 - 0 - 1)(10)

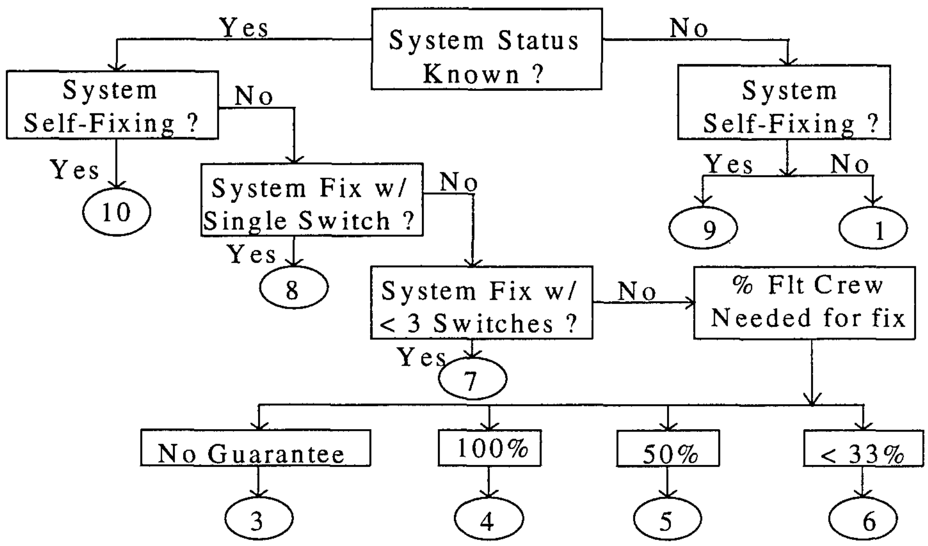
MR = 80

The following table summarizes the results of the Maintenance Requirements Model sample calculations.

Measurable	Raw Score (s)
Initial Maintenance Reliability (IMR)	9
Man-Hours (H)	1
Facilities (F)	0
Equipment (E)	0
Special Handling (SH)	0
Testing (T1 & T2)	1 & 0

Operator Tasking Model

The system status is known by the lighting color on the control panel. The system is self-fixing as it constantly maintains status and does periodic reinitialization.



Rating: 10

Appendix C: Targeting Simulation Results

The task of defending a sphere with a 30.48 m (100 ft) radius around an aircraft is very difficult. During Iteration Two, the GSE-95D Systems Engineering Team tests an hypothesis that the actual area which needs to be defended is far less than the entire surface area of the sphere. In order to find the actual surface area which needs protection, simulations of basic missile launch scenarios are run. Based on aircraft symmetry, only launch angles, defined as angle "A" in Figure 5.1 (azimuth), from 0° to 180° are considered. The 180° missile launch area is divided into twenty zones, each nine degrees wide. 250 simulations are run for each zone with the launch angle being randonly generated within the zone and the launch range being generated using a Rayliegh distribution with the minimum value allowed being 3000 feet and the mean set to 4000 feet. All areas within 3000 feet are assumed to be secure. Figure E1 Displays the 20 launch regions and the distribution of launches within each region. The range distribution of the simulations, as well as the ideal range distribution is presented in Figure E2. Graphics presenting the location on the 30.48 m (100 ft) sphere at which the aircraft-missile intercept occurs are shown in Figures E3 (top view), E4 (side view), and E5 (rear view).

The simulations indicate that the azimuth angle at which the missiles intercept the 30.48 m (100 ft) radius sphere is normally further aft of the aircraft relative to the angle at which the missile is launched. In other words, referencing Figure E1 and Figure E3, if a missile is launched from zone 17 or 18, it will enter the 30.48 m (100 ft) sphere in a lower

numbered zone such as 15 or 16. The average launch angle is 90°, but the missile enters the 30.48 m (100 ft) radius sphere at an average of 97.7°. Figure E6 presents the distribution of aircraft-missile intercepts throughout the 20 zones (azimuth) as a function of elevation which support the average shift from 90° to 97.7°.

The simulations also indicate that elevation of the missile relative to the aircraft had a Gaussian distirbution with a mean of 93.12° and a standard deviation of 0.67°. This distribution in presented in Figure E7. This supports the hypothesis that instead of having to defend the entire 30.48 m (100 ft) radius sphere, there is a well defined hoop just below the aircraft that must be defended. This knowledge allows the GSE-95D Systems Engineering Team to assume that the target elevation at which to launch the expendable is constant.

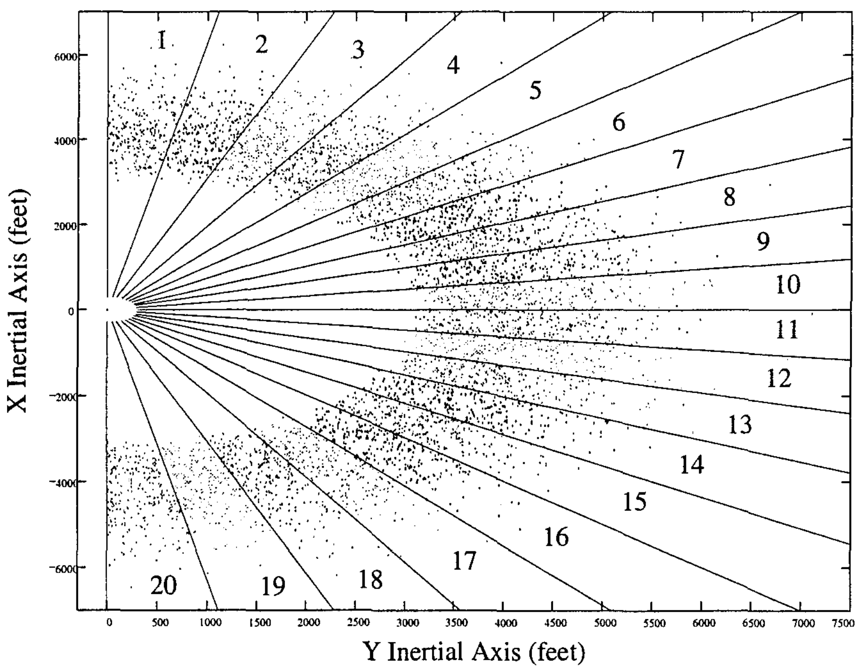


FIGURE C1 Missile Launch Azimuth Distribution

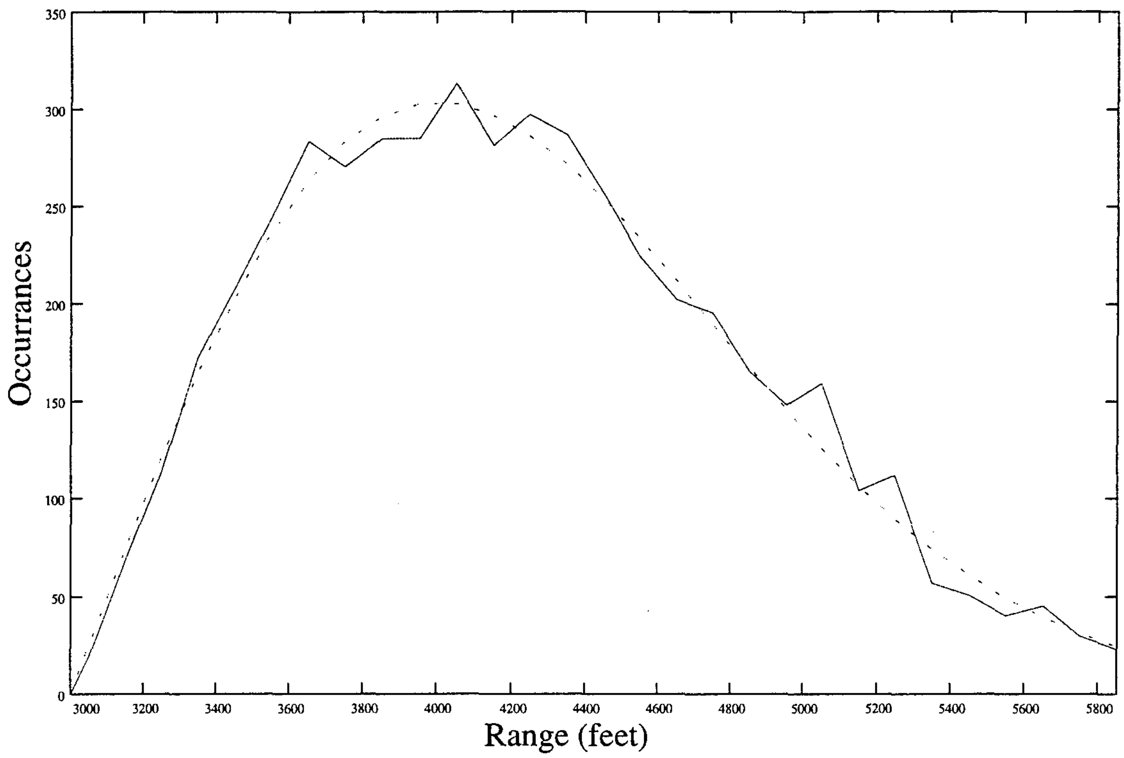


FIGURE C2 Missile Launch Range Distribution

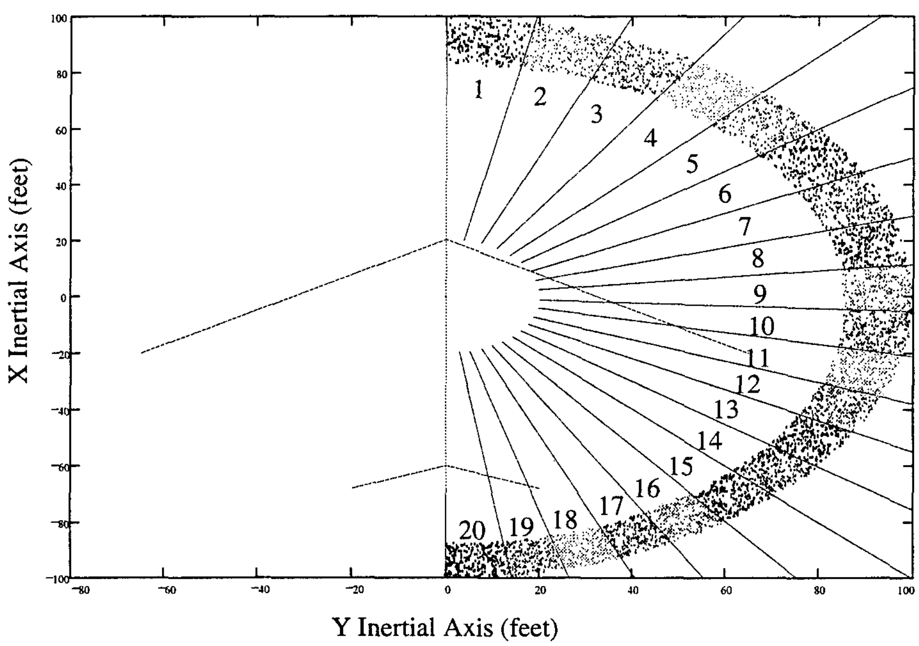


FIGURE C3 Aircraft-Missile Intercept Distribution (Top View)

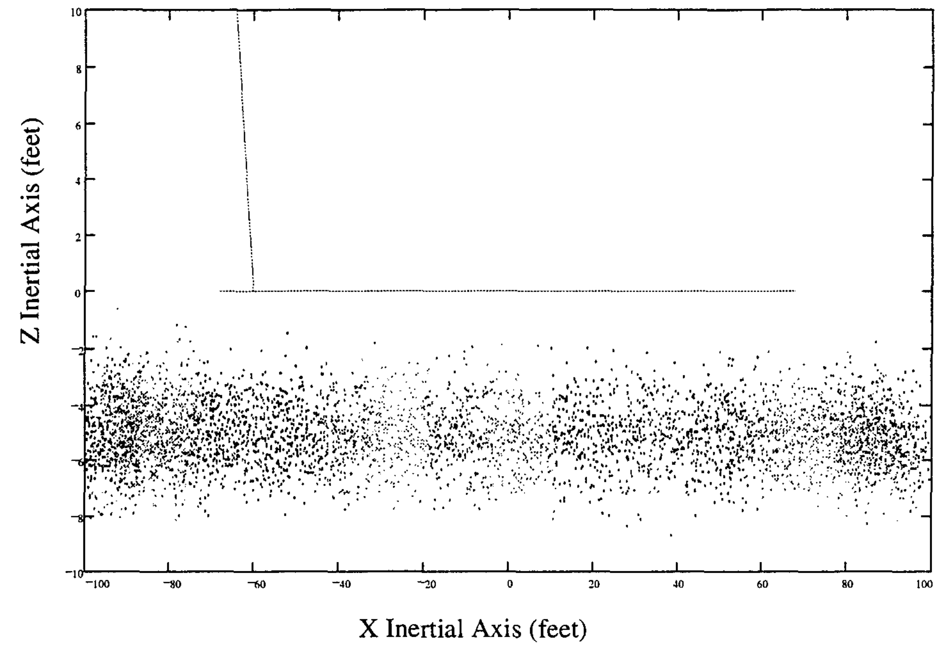


FIGURE C4 Aircraft-Missile Intercept Distribution (Side View)

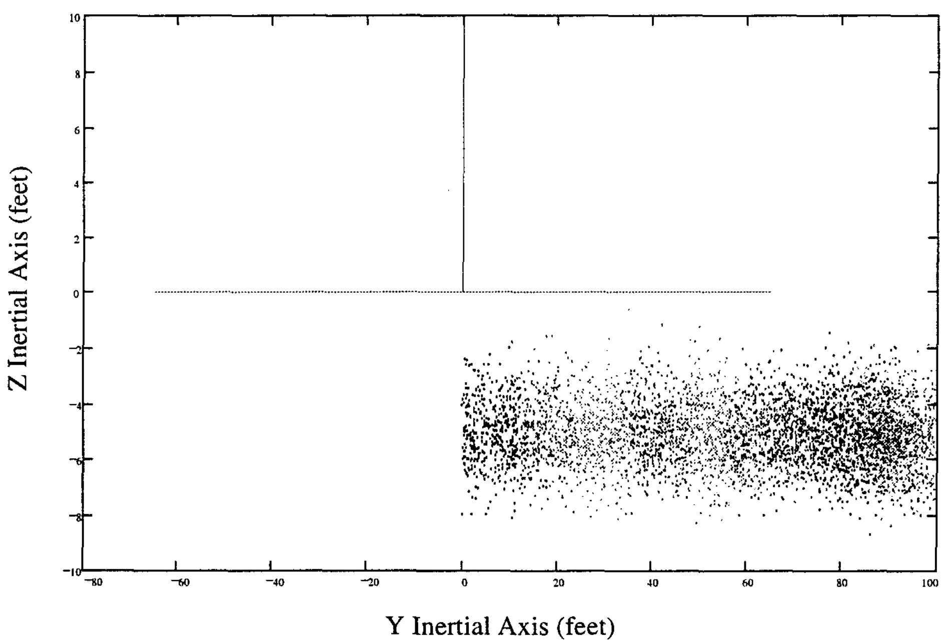


FIGURE C5 Aircraft-Missile Intercept Distribution (Rear View)

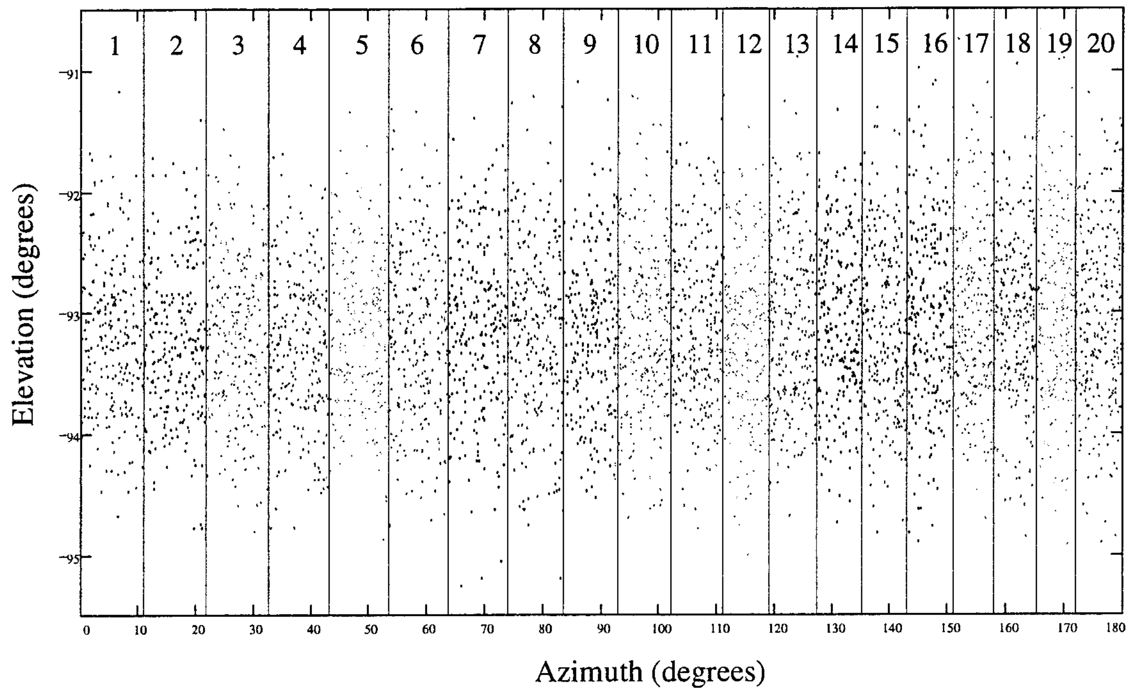


FIGURE C6 Aircraft-Missile Intercept

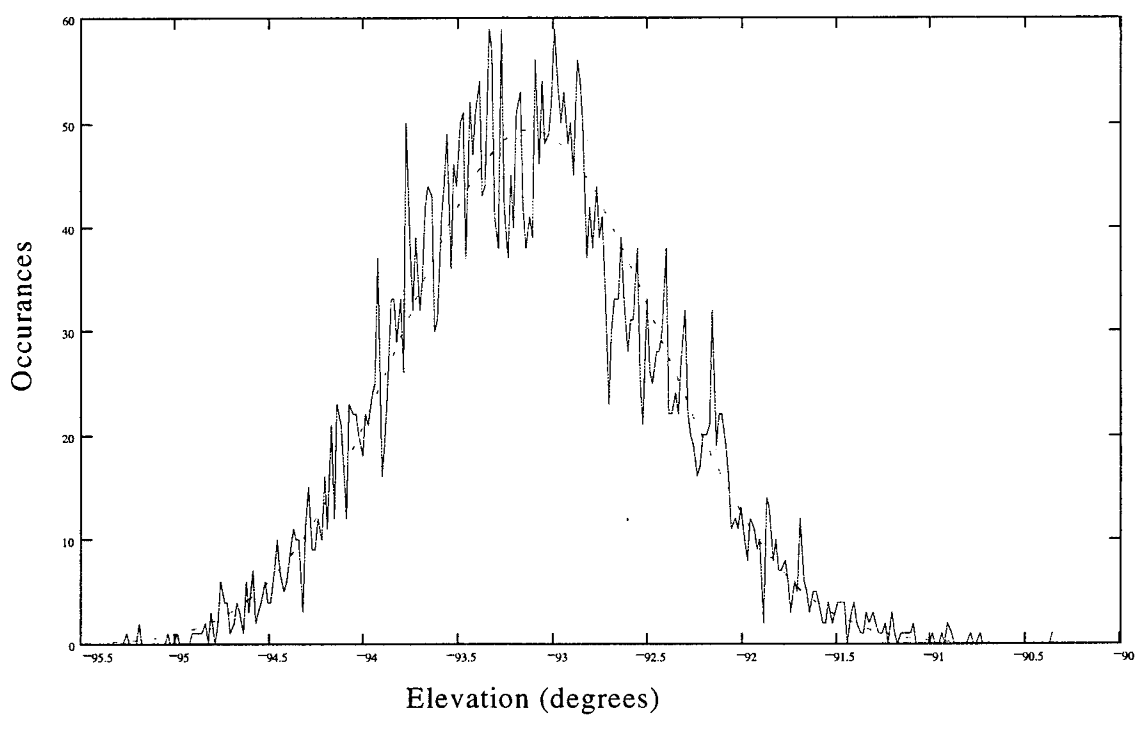


FIGURE C7 Aircraft-Missile Intercept Elevation Angle

Appendix D: Utility Charts

Effectiveness Model

Probability of Kill

PK	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Utility	100	80	60	40	30	20	15	10	5	1

Environmental Impact Model

Harmful Air Pollutants (Humans)

Temp (Celsius)	0-25	25-50	50-75	75-100	100-125	125 +
Utility	100	80	50	30	10	1

Harmful Air Pollutants (Animals)

Temp (Celsius)	0-100	100-150	150-200	200-250	250-300	300+
Utility	100	90	60	40	10	1

Harmful Air Pollutants (Plants)

Kinetic Energy (N/m)	0-0.001	0.001-0.01	0.01-0.1	0.1-1	1-10	10 +
Utility	100	80	60	40	20	1

Colateral Damage - Temperature (Humans)

Kinetic Energy (N/m)	0-0.01	0.01-0.1	0.1-1	1-10	10-100	100+
Utility	100	80	60	40	20	1

Colateral Damage - Temperature (Property)

Effect	No Effect	Discomfort	Illness	Lethal
Utility	100	90	50	0

Colateral Damage - Kinetic Energy (Humans)

Effect	No Effect	Discomfort	Illness	Lethal
Utility	100	90	50	0

Colateral Damage - Kinetic Energy (Property)

Effect	No Effect	Discoloration	Disease	Lethal
Utility	100	90	50	0

Impact on Aircraft Model

Displacement

Displacement (cu. cm)	< 1	1-5	5-15	15-20	20-50	> 50
Utility	100	80	60	40	20	1

Weight

Weight (N)	< 100	100-500	500-1000	1000-1500	1500-2000	> 2000
Utility	100	80	60	40	20	1

Number of Interfaces

Number of Interfaces	None	1	3	5	7	9	> 9
Utility	100	90	70	50	30	10	1

Power

Power Required	yes	no
Utility	100	0

Center of Gravity

Center of Gravity	0	0-0.1	0.1-0.2	0.2-0.4	0.4-0.8	> 0.8
Utility	100	80	60	40	20	1

Impact on Mission Model

Range

Range	< 100	100-200	200-500	500-1000	1000-2000	> 2000
Utility	100	80	60	40	20	1

Endurance

Endurance	< 10	10-15	15-20	20-30	30-40	> 40
Utility	100	80	60	40	20	1

System Isolation

System Isolation	yes	no
Utlity	100	0

On-Time Takeoff

On-Time Takeoff	yes	no
Utility	100	0

Installation Requirements Model

Man-Hours

Man-Hours	<2400	2400-3600	3600-4800	4800-6000	6000-7200	7200-9000	> 9000
Utility	100	80	60	40	20	10	1

Personnel

Personnel	0	1	2	3	4	5	6	7	8	9	> 9
Utility	100	90	80	70	60	50	40	30	20	10	1

Life Cylce Cost Model

RDTE Costs

RDTE Cost ($ million)	0-1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	> 11
Utility	100	95	90	85	80	75	70	65	60	50	40	30

Acquisition Costs

Acq Cost ($ 100K)	< 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	> 12
Utility	100	95	90	85	80	75	70	60	50	40

Operations Costs

Ops Cost ($ 10K)	< 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	> 8
Utility	100	95	90	85	80	60	40	30

Disposal Costs

Disp Cost ($ 10K)		< 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	> 8
Utility		100	95	90	85	80	60	40	30

Operator Tasking Model

Evaluation Scale

Eval Scale	10	9	8	7	6	5	4	3	2	1
Utility	100	90	80	70	60	50	40	30	20	10

SYSTEM - Tracker 1, Air Bag, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	16.00	4.88	0.80	3.90
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	70.00	0.70	1.00	0.70
Endurance	0.02000	30.00	0.60	1.00	0.60
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	42.50	0.51	1.00	0.51
Property Damage	0.00300	42.50	0.13	1.00	0.13
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			60.56	0.99	59.59

SYSTEM - Tracker 2, Air Bag, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	85.00	5.53	1.00	5.53
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	30.00	0.63	1.00	0.63
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	16.30	4.97	0.90	4.47
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	70.00	0.70	1.00	0.70
Endurance	0.02000	30.00	0.60	1.00	0.60
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	42.50	0.51	1.00	0.51
Property Damage	0.00300	42.50	0.13	1.00	0.13
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			59.47	1.00	58.97

SYSTEM - Tracker 3, Air Bag, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	60.00	3.90	1.00	3.90
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	30.00	0.63	1.00	0.63
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	62.00	18.91	0.90	17.02
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	70.00	0.70	1.00	0.70
Endurance	0.02000	30.00	0.60	1.00	0.60
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	42.50	0.51	1.00	0.51
Property Damage	0.00300	42.50	0.13	1.00	0.13
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			70.96	1.00	69.07

SYSTEM - Detector, Air Bag, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.50	0.15	0.90	0.14
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	70.00	0.70	1.00	0.70
Endurance	0.02000	30.00	0.60	1.00	0.60
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	42.50	0.51	1.00	0.51
Property Damage	0.00300	42.50	0.13	1.00	0.13
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			54.44	1.00	54.42

SYSTEM - Tracker 1, Air Bag, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	60.00	0.84	1.00	0.84
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.80	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	1.00	1.02
Property Damage	0.00300	85.00	0.26	1.00	0.26
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			61.62	0.99	61.62

SYSTEM - Tracker 2, Air Bag, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	60.00	0.84	1.00	0.84
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.90	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	1.00	1.02
Property Damage	0.00300	85.00	0.26	1.00	0.26
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			61.62	1.00	61.62

SYSTEM - Tracker 3, Air Bag, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	70.00	4.55	1.00	4.55
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	60.00	0.84	1.00	0.84
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	76.00	23.18	0.90	20.86
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	1.00	1.02
Property Damage	0.00300	85.00	0.26	1.00	0.26
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			82.03	1.00	79.71

SYSTEM - Detector, Air Bag, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	60.00	0.84	1.00	0.84
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.50	0.15	0.90	0.14
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	1.00	1.02
Property Damage	0.00300	85.00	0.26	1.00	0.26
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			60.37	1.00	60.36

SYSTEM - Tracker 1, Cherry Bomb, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	50.00	1.05	1.00	1.05
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	97.30	29.68	1.00	29.68
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	80.00	0.80	1.00	0.80
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	42.50	0.54	1.00	0.54
Animals	0.00150	42.50	0.06	1.00	0.06
Plant Life	0.00075	42.50	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	47.50	0.57	1.00	0.57
Property Damage	0.00300	47.50	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			83.78	1.00	83.78

SYSTEM - Tracker 2, Cherry Bomb, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	85.00	5.53	1.00	5.53
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	98.00	29.89	1.00	29.89
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	80.00	0.80	1.00	0.80
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	42.50	0.54	1.00	0.54
Animals	0.00150	42.50	0.06	1.00	0.06
Plant Life	0.00075	42.50	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	47.50	0.57	1.00	0.57
Property Damage	0.00300	47.50	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			82.81	1.00	82.81

SYSTEM - Tracker 3, Cherry Bomb, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	60.00	3.90	1.00	3.90
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	100.00	30.50	1.00	30.50
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	80.00	0.80	1.00	0.80
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	42.50	0.54	1.00	0.54
Animals	0.00150	42.50	0.06	1.00	0.06
Plant Life	0.00075	42.50	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	47.50	0.57	1.00	0.57
Property Damage	0.00300	47.50	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			80.97	1.00	80.97

SYSTEM - Detector, Cherry Bomb, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	50.00	1.05	1.00	1.05
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.90	0.27	1.00	0.27
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	80.00	0.80	1.00	0.80
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	42.50	0.54	1.00	0.54
Animals	0.00150	42.50	0.06	1.00	0.06
Plant Life	0.00075	42.50	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	47.50	0.57	1.00	0.57
Property Damage	0.00300	47.50	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			52.97	1.00	52.97

SYSTEM - Tracker 1, Cherry Bomb, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.10	0.03	1.00	0.03
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	1.00	1.08
Animals	0.00150	85.00	0.13	1.00	0.13
Plant Life	0.00075	85.00	0.06	1.00	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	95.00	1.14	1.00	1.14
Property Damage	0.00300	95.00	0.29	1.00	0.29
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			61.11	1.00	61.11

SYSTEM - Tracker 2, Cherry Bomb, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	1.20	0.37	1.00	0.37
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	1.00	1.08
Animals	0.00150	85.00	0.13	1.00	0.13
Plant Life	0.00075	85.00	0.06	1.00	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	95.00	1.14	1.00	1.14
Property Damage	0.00300	95.00	0.29	1.00	0.29
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			61.45	1.00	61.45

SYSTEM - Tracker 3, Cherry Bomb, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	70.00	4.55	1.00	4.55
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	98.00	29.89	1.00	29.89
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	1.00	1.08
Animals	0.00150	85.00	0.13	1.00	0.13
Plant Life	0.00075	85.00	0.06	1.00	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	95.00	1.14	1.00	1.14
Property Damage	0.00300	95.00	0.29	1.00	0.29
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			88.20	1.00	88.20

SYSTEM - Detector, Cherry Bomb, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	90.00	5.85	1.00	5.85
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	1.00	1.08
Animals	0.00150	85.00	0.13	1.00	0.13
Plant Life	0.00075	85.00	0.06	1.00	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	95.00	1.14	1.00	1.14
Property Damage	0.00300	95.00	0.29	1.00	0.29
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			59.68	1.00	59.68

SYSTEM - Tracker 1, Det Net, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	40.00	0.56	1.00	0.56
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	39.50	12.05	1.00	12.05
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	45.00	0.57	1.00	0.57
Animals	0.00150	45.00	0.07	1.00	0.07
Plant Life	0.00075	45.00	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			68.03	1.00	68.03

SYSTEM - Tracker 2, Det Net,Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	90.00	5.85	1.00	5.85
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	40.00	0.56	1.00	0.56
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	39.25	11.97	1.00	11.97
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	45.00	0.57	1.00	0.57
Animals	0.00150	45.00	0.07	1.00	0.07
Plant Life	0.00075	45.00	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			67.30	1.00	67.30

SYSTEM - Tracker 3, Det Net,Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	60.00	3.90	1.00	3.90
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	40.00	0.56	1.00	0.56
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	97.50	29.74	1.00	29.74
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	45.00	0.57	1.00	0.57
Animals	0.00150	45.00	0.07	1.00	0.07
Plant Life	0.00075	45.00	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			82.29	1.00	82.29

SYSTEM - Detector, Det Net, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	50.00	1.05	1.00	1.05
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	40.00	0.56	1.00	0.56
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.90	0.27	1.00	0.27
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	45.00	0.57	1.00	0.57
Animals	0.00150	45.00	0.07	1.00	0.07
Plant Life	0.00075	45.00	0.03	1.00	0.03
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			55.06	1.00	55.06

SYSTEM - Tracker 1, Det Net, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	1.00	1.15
Animals	0.00150	90.00	0.14	1.00	0.14
Plant Life	0.00075	90.00	0.07	1.00	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			62.26	1.00	62.26

SYSTEM - Tracker 2, Det Net, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	90.00	5.85	1.00	5.85
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	1.00	1.15
Animals	0.00150	90.00	0.14	1.00	0.14
Plant Life	0.00075	90.00	0.07	1.00	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			59.26	1.00	59.26

SYSTEM - Tracker 3, Det Net, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	1.00	5.85
Acquisition Cost	0.06500	70.00	4.55	1.00	4.55
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	96.00	29.28	1.00	29.28
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	1.00	1.15
Animals	0.00150	90.00	0.14	1.00	0.14
Plant Life	0.00075	90.00	0.07	1.00	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			88.76	1.00	88.76

SYSTEM - Detector, Det Net, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.90	0.27	1.00	0.27
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	1.00	1.15
Animals	0.00150	90.00	0.14	1.00	0.14
Plant Life	0.00075	90.00	0.07	1.00	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	100.00	1.20	1.00	1.20
Property Damage	0.00300	100.00	0.30	1.00	0.30
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			62.75	1.00	62.75

SYSTEM - Tracker 1, SpecNet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	60.00	18.30	0.80	14.64
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	45.00	0.54	1.00	0.54
Property Damage	0.00300	45.00	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			73.17	0.99	69.51

SYSTEM - Tracker 2, SpecNet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	85.00	5.53	1.00	5.53
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	50.00	15.25	0.90	13.73
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	45.00	0.54	1.00	0.54
Property Damage	0.00300	45.00	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			69.14	1.00	67.62

SYSTEM - Tracker 3, SpecNet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	60.00	3.90	1.00	3.90
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	80.00	5.20	1.00	5.20
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	40.00	0.84	1.00	0.84
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	100.00	30.50	0.90	27.45
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	45.00	0.54	1.00	0.54
Property Damage	0.00300	45.00	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			81.94	1.00	78.89

SYSTEM - Detector, SpecNet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	50.00	1.05	1.00	1.05
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	30.00	0.42	1.00	0.42
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	1.00	0.31	0.90	0.27
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	90.00	0.90	1.00	0.90
Endurance	0.02000	40.00	0.80	1.00	0.80
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	45.00	0.54	1.00	0.54
Property Damage	0.00300	45.00	0.14	1.00	0.14
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	20.00	0.56	1.00	0.56
Personnel Req'd	0.01200	50.00	0.60	1.00	0.60
TOTALS			53.98	1.00	53.95

SYSTEM - Tracker 1, SpecNet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.80	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	1.00	1.08
Property Damage	0.00300	90.00	0.27	1.00	0.27
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			60.58	0.99	60.58

SYSTEM - Tracker 2, SpecNet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.30	0.09	0.90	0.08
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	1.00	1.08
Property Damage	0.00300	90.00	0.27	1.00	0.27
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			60.67	1.00	60.66

SYSTEM - Tracker 3, SpecNet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	70.00	4.55	1.00	4.55
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	80.00	5.20	1.00	5.20
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	98.00	29.89	0.90	26.90
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	1.00	1.08
Property Damage	0.00300	90.00	0.27	1.00	0.27
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			87.70	1.00	84.71

SYSTEM - Detector, SpecNet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	1.00	5.20
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	95.00	6.18	1.00	6.18
Disposal Cost	0.06500	85.00	5.53	1.00	5.53
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.90	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	1.00	1.08
Property Damage	0.00300	90.00	0.27	1.00	0.27
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	60.00	1.68	1.00	1.68
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			59.18	1.00	59.18

SYSTEM - Tracker 1, Bullet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.50	0.15	1.00	0.15
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	41.00	0.49	1.00	0.49
Property Damage	0.00300	41.00	0.12	1.00	0.12
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			55.75	1.00	55.75

SYSTEM - Tracker 2, Bullet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	90.00	5.85	1.00	5.85
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.10	0.03	1.00	0.03
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	41.00	0.49	1.00	0.49
Property Damage	0.00300	41.00	0.12	1.00	0.12
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			54.98	1.00	54.98

SYSTEM - Tracker 3, Bullet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	60.00	3.90	1.00	3.90
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.30	0.09	1.00	0.09
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	41.00	0.49	1.00	0.49
Property Damage	0.00300	41.00	0.12	1.00	0.12
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			52.59	1.00	52.59

SYSTEM - Detector, Bullet, Salvo					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	30.00	0.42	1.00	0.42
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	0.00	0.00	1.00	0.00
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	41.00	0.49	1.00	0.49
Property Damage	0.00300	41.00	0.12	1.00	0.12
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			54.20	1.00	54.20

SYSTEM - Tracker 1, Bullet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	82.00	0.98	1.00	0.98
Property Damage	0.00300	82.00	0.25	1.00	0.25
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			57.26	1.00	57.26

SYSTEM - Tracker 2, Bullet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	82.00	0.98	1.00	0.98
Property Damage	0.00300	82.00	0.25	1.00	0.25
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			57.26	1.00	57.26

SYSTEM - Tracker 3, Bullet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	70.00	4.55	1.00	4.55
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.20	0.06	1.00	0.06
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	1.00	2.45
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	82.00	0.98	1.00	0.98
Property Damage	0.00300	82.00	0.25	1.00	0.25
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			54.87	1.00	54.87

SYSTEM - Detector, Bullet, Single					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	100.00	6.50	1.00	6.50
Acquisition Cost	0.06500	100.00	6.50	1.00	6.50
Operational Cost	0.06500	100.00	6.50	1.00	6.50
Disposal Cost	0.06500	100.00	6.50	1.00	6.50
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	70.00	1.47	1.00	1.47
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	1.00	0.00
Passivity	0.01000	100.00	1.00	1.00	1.00
PFalse Alarm	0.03500	30.00	1.05	1.00	1.05
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	90.00	1.80	1.00	1.80
System Isolation	0.04000	0.00	0.00	1.00	0.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	1.00	1.28
Animals	0.00150	100.00	0.15	1.00	0.15
Plant Life	0.00075	100.00	0.08	1.00	0.08
Collateral Damage	0.01500				
Human Injury	0.01200	82.00	0.98	1.00	0.98
Property Damage	0.00300	82.00	0.25	1.00	0.25
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	100.00	0.70	1.00	0.70
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	100.00	1.40	1.00	1.40
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	1.00	1.40
Personnel Req'd	0.01200	70.00	0.84	1.00	0.84
TOTALS			55.86	1.00	55.86

SYSTEM - Anit-Missile Missile					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	30.00	1.95	1.00	1.95
Acquisition Cost	0.06500	40.00	2.60	1.00	2.60
Operational Cost	0.06500	80.00	5.20	1.00	5.20
Disposal Cost	0.06500	30.00	1.95	1.00	1.95
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	100.00	2.10	1.00	2.10
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	30.00	0.21	1.00	0.21
CG Travel	0.01400	80.00	1.12	1.00	1.12
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	80.00	6.40	1.00	6.40
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	60.00	18.30	1.00	18.30
Passivity	0.01000	0.00	0.00	1.00	0.00
PFalse Alarm	0.03500	50.00	1.75	1.00	1.75
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	95.00	1.21	1.00	1.21
Animals	0.00150	95.00	0.14	1.00	0.14
Plant Life	0.00075	95.00	0.07	1.00	0.07
Collateral Damage	0.01500				0.00
Human Injury	0.01200	80.00	0.96	1.00	0.96
Property Damage	0.00300	80.00	0.24	1.00	0.24
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	100.00	2.80	1.00	2.80
Personnel Req'd	0.01200	80.00	0.96	1.00	0.96
TOTALS			62.39	1.00	62.39

Iteration 3

SYSTEM - Tracker 3 (revised), Cherry Bomb					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	0.60	3.51
Acquisition Cost	0.06500	60.00	3.90	0.80	3.12
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	85.00	5.53	0.90	4.97
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.90	0.00
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	0.90	0.98
Animals	0.00150	85.00	0.13	0.90	0.11
Plant Life	0.00075	85.00	0.06	0.90	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	70.00	0.84	0.60	0.50
Property Damage	0.00300	90.00	0.27	0.60	0.16
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			57.15	0.90	51.24

SYSTEM - Tracker 3, DetNet					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	0.60	3.12
Acquisition Cost	0.06500	60.00	3.90	0.90	3.51
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	80.00	5.20	0.90	4.68
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	82.00	25.01	0.90	22.51
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	0.90	1.03
Animals	0.00150	90.00	0.14	0.90	0.12
Plant Life	0.00075	90.00	0.07	0.90	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	0.60	0.65
Property Damage	0.00300	100.00	0.30	0.60	0.18
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			79.23	0.91	71.38

SYSTEM - Tracker 3 (revised), SpecNet					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	0.60	3.51
Acquisition Cost	0.06500	60.00	3.90	0.90	3.51
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	85.00	5.53	0.90	4.97
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	70.00	21.35	0.90	19.22
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	0.90	1.15
Animals	0.00150	100.00	0.15	0.90	0.14
Plant Life	0.00075	100.00	0.08	0.90	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	0.60	0.61
Property Damage	0.00300	85.00	0.26	0.60	0.15
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			78.89	0.91	71.15

SYSTEM - Tracker 2a, Cherry Bomb					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	0.60	3.51
Acquisition Cost	0.06500	100.00	6.50	0.70	4.55
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	90.00	5.85	0.90	5.27
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	0.00	0.00	0.90	0.00
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	85.00	1.08	0.90	0.98
Animals	0.00150	85.00	0.13	0.90	0.11
Plant Life	0.00075	85.00	0.06	0.90	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	70.00	0.84	0.60	0.50
Property Damage	0.00300	90.00	0.27	0.60	0.16
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	0.00	0.00	1.00	0.00
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			60.07	0.90	52.96

SYSTEM - Tracker 2a, DetNet					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	80.00	5.20	0.60	3.12
Acquisition Cost	0.06500	100.00	6.50	0.80	5.20
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	85.00	5.53	0.90	4.97
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	100.00	1.40	1.00	1.40
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	82.00	25.01	0.90	22.51
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	0.00	0.00	1.00	0.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	90.00	1.15	0.90	1.03
Animals	0.00150	90.00	0.14	0.90	0.12
Plant Life	0.00075	90.00	0.07	0.90	0.06
Collateral Damage	0.01500				
Human Injury	0.01200	90.00	1.08	0.60	0.65
Property Damage	0.00300	100.00	0.30	0.60	0.18
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			82.15	0.90	73.37

SYSTEM - Tracker 2a, SpecNet					
Measurable	Weight	Utility	Raw Score	Confidence	Discounted Score
COST	0.26000				
RDT&E Cost	0.06500	90.00	5.85	0.60	3.51
Acquisition Cost	0.06500	100.00	6.50	0.80	5.20
Operational Cost	0.06500	95.00	6.18	0.90	5.56
Disposal Cost	0.06500	90.00	5.85	0.90	5.27
IMPACT ON A/C	0.07000				
Displacement	0.01400	80.00	1.12	1.00	1.12
Weight	0.02100	90.00	1.89	1.00	1.89
Power	0.01400	100.00	1.40	1.00	1.40
Interfaces	0.00700	50.00	0.35	1.00	0.35
CG Travel	0.01400	50.00	0.70	1.00	0.70
OPERATOR TASKING	0.08000				
Tasking Steps	0.08000	100.00	8.00	1.00	8.00
EFFECTIVENESS	0.35000				
Prob. of Kill of missile	0.30500	70.00	21.35	0.90	19.22
Passivity	0.01000	50.00	0.50	1.00	0.50
PFalse Alarm	0.03500	70.00	2.45	0.90	2.21
MISSION IMPACT	0.10000				
Range	0.01000	100.00	1.00	1.00	1.00
Endurance	0.02000	100.00	2.00	1.00	2.00
System Isolation	0.04000	100.00	4.00	1.00	4.00
On-time Capability	0.03000	100.00	3.00	1.00	3.00
ENVIRON. IMPACT	0.03000				
Harmful Air Effects	0.01500				
Humans	0.01275	100.00	1.28	0.90	1.15
Animals	0.00150	100.00	0.15	0.90	0.14
Plant Life	0.00075	100.00	0.08	0.90	0.07
Collateral Damage	0.01500				
Human Injury	0.01200	85.00	1.02	0.60	0.61
Property Damage	0.00300	85.00	0.26	0.60	0.15
MAINTENANCE REQ'S	0.07000				
Reliability	0.02800	100.00	2.80	1.00	2.80
Man-Hours/week	0.00700	0.00	0.00	1.00	0.00
Facilities	0.00700	100.00	0.70	1.00	0.70
Equipment	0.00700	100.00	0.70	1.00	0.70
Special Handling	0.00700	100.00	0.70	1.00	0.70
Testing	0.01400	0.00	0.00	1.00	0.00
INSTALLATION REQ'S	0.04000				
Man-Hours Req'd	0.02800	50.00	1.40	0.60	0.84
Personnel Req'd	0.01200	50.00	0.60	0.60	0.36
TOTALS			81.81	0.90	73.13

Appendix F: Iteration Two and Three Evaluation Results

Iteration Two

Defense System	Raw Score	Discounted Score
D-Cherry Bomb-Single	59.68	59.68
D-DetNet-Single	62.75	62.75
D-Bullet-Single	55.86	55.86
D-SpecNet-Single	59.18	59.18
D-AirBag-Single	60.37	60.36
D-Cherry Bomb-Multiple	52.97	52.97
D-DetNet-Multiple	55.06	55.06
D-Bullet-Multiple	54.2	54.2
D-SpecNet-Multiple	53.98	53.95
D-AirBag-Multiple	54.55	54.42
T1-Cherry Bomb-Single	61.11	61.11
T1-DetNet-Single	62.26	62.26
T1-Bullet-Single	57.26	57.26
T1-SpecNet-Single	60.58	60.58
T1-AirBag-Single	61.62	61.62
T1-Cherry Bomb-Multiple	83.78	83.78
T1-DetNet-Multiple	68.03	68.03
T1-Bullet-Multiple	55.75	55.75
T1-SpecNet-Multiple	73.17	69.51
T1-AirBag-Multiple	60.56	59.59
T2-Cherry Bomb-Single	61.45	61.45
T2-DetNet-Single	59.26	59.26
T2-Bullet-Single	57.26	57.26
T2-SpecNet-Single	60.67	60.66
T2-AirBag-Single	61.62	61.62
T2-Cherry Bomb-Multiple	82.81	82.81
T2-DetNet-Multiple	67.3	67.3
T2-Bullet-Multiple	54.98	54.98
T2-SpecNet-Multiple	69.14	67.62
T2-AirBag-Multiple	59.47	58.97
T3-Cherry Bomb-Single	88.2	88.2
T3-DetNet-Single	88.76	88.76
T3-Bullet-Single	54.87	54.87
T3-SpecNet-Single	87.7	84.71
T3-AirBag-Single	82.03	79.71
T3-Cherry Bomb-Multiple	80.97	80.97
T3-DetNet-Multiple	82.29	82.29
T3-Bullet-Multiple	52.59	52.59
T3-SpecNet-Multiple	81.94	78.89
T3-AirBag-Multiple	70.96	69.07
AMM	62.39	62.39

Iteration Three

Defense System	Raw Score	Discounted Score
T3-Cherry Bomb	57.15	51.239
T2a-Cherry Bomb	60.07	52.961
T3-Det-Net	79.23	71.385
T2a-Det-Net	82.15	73.367
T3-Spec-Net	78.89	71.145
T2a-Spec-Net	81.81	73.128

Bibliography

1. Austin, Donna. Test Engineer, 413 Test / Engineering Squadron, USAF FTC, Edwards AFB CA. Telephone interview. 10 May 1995.

2. Bandstra, Robert W. Stability of Spinning ICBM in First Boost Phase. MS thesis, AFIT/GA/AA/85D-01. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1985 (AD-A164019).

3. "Bell AH1 Cobra/Super Cobra." Jane's All the Worlds Aircraft. Alexandria VA: Jane's Information Group, 1993-1994.

4. Boyer, L. L. III, Project Engineer. "Polyphemus." A briefing to the Electronic Warfare Division of Wright Laboratory. Wright Laboratory, Wright-Patterson AFB OH, 12 July 1994.

5. Brunhelder, D. Project Engineer, ASC/ENFZ, Wright-Patterson AFB OH. Personal interview. 23 June 1995 & 12 July 1995.

6. Burgan, Daryl. Professor of Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH. Personal interview. 18 April 1995.

7. Burggraf, L. Professor of Chemistry, Air Force Institute of Technology, Wright-Patterson AFB OH. Personal interview. 17 April 1995.

8. Doherty, Robert. Missile Analyst, Missile and Space Intelligence Command, Huntsville AL. Telephone interview. 20 July 1995.

9. Franke, Milton E. Class handout, SENG 564, Conventional Weapons Effects. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH. October 1994.

10. Fulghum, David A. "AMRAAM Upgrade for Quick Single-Shot MIG-29 Kills," Aviation Week & Space Technology, 57-59 (21 June 1993).

11. Handbook of Mathematical Scientific and Engineering Formulas. New York: Research & Education Association, 1980.

12. Hoerner, Sighard F. Fluid-Dynamic Drag: Practical Information on Aerodynamic Drag and Hydrodynamic Resistance. Midland Park NJ: Hoerner, 1958.

13. Hoffman, Eric. Project Officer, Naval Surface Warfare Center, Indian Head MD. Phone interview. 22 June 1995.

14. Hughes, David. "Army EH-60 to flight Test Sanders Directed IR Jammer," Aviation Week & Space Technology, 57-60 (28 March 1994).

15. Hughes, David. "FAA Examine Missile Threat," Aviation Week & Space Technology, 31-32 (16 August 1993).

16. Kramer, Stuart. Class Handout, SE520, Introduction to Systems Engineering. School of Engineering, Air Force Institute of Technology, Wrigh-Patterson AFB, OH, Fall 1994.

17. Lindeburg, Michael R. Engineering In Training Review Manual: Sixth Edition. San Carlos CA: Professional Publications, 1982.

18. Macfadzean, Robert H. Surface Based Air Defense System Analysis. Boston: Artech House, 1992.

19. Mangolds, Arnis. Manager, Federal Systems Design & Systems Integration, Foster-Miller Inc. Waltham MA. Telephone interview. 9 May - 1 August 1995.

20. Morrocco, John D. "Self-Protection Systems Added to Relief C-130s," Aviation Week & Space Technology, 42-43 (12 July 1993).

21. Nordwall, Bruce D. "Northrop Developing Laser to Jam IR-Guided Missile," Aviation Week & Space Technology, 61-62 (5 July 1993).

22. Parker, Earl R. Materials Data Book. New York: McGraw-Hill Book Co. , 1967.

23. Roskam, Jan. Airplane Design Part VII: Airplane Cost Estimation - Design, 22. Development, Manufacturing and Operations. Ottawa KS: Roskam Aviation & Engineering Corp, 1985.

24. Schaffer, Marvin B. Concerns About Terrorist With Manportable SAMS. Santa Monica CA: Rand Corporation, 1993.

25. "Stinger Missile System" Jane's Weapon Systems. Alexandria VA: Jane's Information Group, 1988 - 1990.

26. Stoddard, Frank J. Program Manager, Propulsion & Combustion Center, TRW Space & Technology Division, Space & Electronics Group, Redondo Beach CA. Telephone interview. 12 May - 13 Oct 1995.

27. Straub, Conrad P. CRC Practical Handbook of Environmental Control. Boca Raton FL: CRC Press, 1989.

28. Voegle, George. Electrical Engineer, Wright Laboratory, Electronic Warfare Division, Wright-Patterson AFB OH. Personal interview. 16 May 1995.

29. "Vulcan Air Defense System" Jane's Weapon Systems. Alexandria VA: Jane's Information Group, 1989-1990.

Vita

Bruce R. DeWitt [redacted]. He graduated from the United States Air Force Academy as a Distinguished Graduate in June 1983 with a Bachelor of Science in Engineering Mechanics. He was commissioned a Second Lieutenant upon graduation and reported to Undergraduate Pilot training at Reeses AFB, Texas. Following UPT, he served as a T-38 Instructor Pilot with the 54th Flying Training Wing. He progressed to his next flying assignment as an Instructor Pilot and Tactical Instructor in the B-52H at Fairchild AFB, Washington in March 1988. In 1990 he was selected to attend the United States Air Force Test Pilot School at Edwards AFB, California. As an experimental test pilot, Major DeWitt served as the chief test pilot for the T-3A Spin program, JPATS Source Selection, Class IIIA Closed Loop Handling Qualities Project, and a multitude of other tests. In 1993 he was selected the US Air Force Tester of the Year while working with the 4950th Test Wing at Wright-Patterson AFB, Ohio. In 1994, he was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, OH. In 1995, he graduated with a Masters of Science Degree in Aeronautical Engineering. Upon graduation, he was assigned to Wright Laboratory at Wright Patterson AFB, OH.

Christopher Greg Dusseault [redacted]. He graduated from Worcester Polytechnic Institute in May 1990 with a Bachelor of Science Degree in Mechanical Engineering. Upon graduation, he was commissioned a Second Lieutenant in the U.S. Air Force. Between 1990 and 1994, Lieutenant Dusseault was assigned to the Air Force Construction Automation Laboratory, Air Force Civil Engineering Support Agency, Tyndall AFB, FL where he served as a Research Mechanical Engineer. In 1994, he was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, OH. In 1995, he graduated with a Masters of Science Degree in Systems Engineering. Upon graduation, he was assigned to the Air Force Operational Test and Evaluation Center at Kirtland AFB, NM.

Joel John Hagan [redacted]. He graduated from Embry-Riddle Aeronautical University in Decmber 1990 with a Bachelor of Science Degree in Aeronautical Engineering. Upon graduation, he was commissioned a Second Lieutenant in the U.S. Air Force. In September 1991, Lieutenant Hagan was assigned to San Antonio Air Logistics Center, Kelly AFB, TX. From September 1991 to May 1993, he served as a Process Improvment Engineer for the Technology and Industrial Support Directorate. From May 1993 to May 1994, he served as an Aerodynamics and Performance Engineer for the Aircraft Directorate. In May 1994, he was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, OH. He graduated in 1995 with a Masters of Science Degree in Aeronauctical Engineering. Upon graduation, he was assigned to Phillips Laboratory at Kirtland AFB, NM.

Mark Christopher Cherry [redacted]

He graduated from the United States Air Force Academy in May 1991 with a Bachelor of Science Degree in Engineering Mechanics. Upon graduation, he was commissioned a Second Lieutenant in the U.S. Air Force. Between Aug 1991 and May 1994, he was assigned to the Air Force Command And Control Networking System Program Office, Standards Systems Center, Maxwell AFB - Gunter Annex, Montgomery AL. There he served as the Deputy Program Manager for Requirements. In May 1994, he was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, OH. In 1995, he graduated with a Masters of Science Degree in Aeronautical Engineering. Upon graduation, he was assigned to Wright Laboratory at Wright Patterson AFB, OH.

Brian Peterson [redacted]. He graduated from the United States Air Force Academy in May 1991 with a Bachelor of Science Degree in Electrical Engineering. Upon graduation, he was commissioned a Second Lieutenant in the U.S. Air Force. He was first assigned to the 84th Test Squadron, Tyndall AFB, FL where he served as a Developmental Test and Evaluation Engineer. In May 1994, he was selected to attend the Air Force Institute of Technology at Wright-Patterson AFB, OH. In 1995, he graduated with a Masters of Science Degree in Systems Engineering. Upon graduation, he was assigned to Phillips Laboratory at Kirtland AFB, NM.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1995	Technical Report; Thesis

4. TITLE AND SUBTITLE

A SYSTEMS ENGINEERING APPROACH TO AIRCRAFT KINETIC KILL COUNTERMEASURES TECHNOLOGY: DEVELOPMENT OF AN ACTIVE AIRCRAFT DEFENSE SYSTEM FOR THE C/KC-135 AIRCRAFT

5. FUNDING NUMBERS

6. AUTHOR(S)

Captain Mark Cherry, Major Bruce DeWitt,
Captain Christopher Dusseault, Captain Joel Hagan
Captain Brian Peterson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GSE/ENG/95D-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

WL/AAWD-2
Wright-Patterson AFB, OH 45433-7521

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Modern Surface to Air Missiles (SAMs) present a significant threat to today's military and civilian aircraft. Current countermeasure systems such as flares and chaff rely on decoying the missile threat and do not provide adequate protection against advanced computerized missiles (Schaffer, 1993:1). An aircraft defense system that actively seeks out and defeats an incoming missile by placing a physical barrier in the missile's path offers a promising alternative to current countermeasures technology. This thesis reports the preliminary design of an active aircraft defense system for the protection of the C/KC-135 aircraft from SAMs. The developed system utilizes a kinetic kill mechanism to protect the aircraft from shoulder launched missiles while the aircraft is in the takeoff and climb-out configurations. Both smart anti-missile expendables and dumb projectile expendables are evaluated. The iterative Systems Engineering approach is used to narrow the solution set to the optimal design. The final outcome is the refined design of two candidate aircraft defense system employing a kinetic kill mechanism. Both systems utilize a modified ultra-violet tracker and employ one of two types of nets, one made out of Detonation Cord and the other made out of Spectra.

14. SUBJECT TERMS

KC-135, Aircraft Defense, Active Aircraft Defense, Kinetic Kill

15. NUMBER OF PAGES

475

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C -	Contract	**PR** -	Project
G -	Grant	**TA** -	Task
PE -	Program Element	**WU** -	Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.